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Designing Socially Acceptable Body-worn Cameras

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To all active bystanders, and those trying to be.
Let's make a difference.

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Abstract

Body-worn cameras, the focus of this thesis, promise a range of benefits, such as object recognition, tracking and visual navigation, but also personal expression and memory keeping. Simultaneously, not only taking pictures, but also not having one's picture taken, can be understood as essential, modern-day right. Thus, bystander's objections and concerns about privacy are serious and legitimate. In consequence, state-of-the-art body-worn camera devices lack *social acceptability*: they are not designed to address conflicts of interest between device user and their bystanders. This work targets *social acceptability issues* with body-worn cameras by identifying both the users' and the bystanders' *needs, goals and values*, and by addressing them through *human-centered design (HCD)*.

To date, HCD only sparsely provides methods and best practices to attend to *social acceptability issues*. In particular, social acceptability issues are often considered only after deployment, which may lead to costly re-design of interfaces, or increase the stigmatization of users. Starting out from the example of body-worn cameras, my thesis challenges interface design to attend to *social acceptability* issues not after deployment, but during all phases of the *HCD* process. To this aim, this thesis makes three main contributions:

First, I analyze how *social acceptability* and *social acceptance* are approached by state-of-the art research in human-computer interaction. Based on a structured literature review, I provide a detailed overview of existing methods, measures and design strategies and how they are employed to evaluate, quantify, and influence the social acceptability of human-machine interfaces. Most significantly, my analysis identifies an unbalanced distribution of study approaches and a lack of interlacing between empirical and artifact-creating approaches.

Second, I explore how the design of body-worn cameras can meet both the user's and the bystander's *needs, goals, and values*. Cycling through each phase of an exemplary *HCD* process, I investigate user attitudes, concerns and expectations regarding body-worn cameras (phase 1), explore design options (phase 2), prototype smart wearable cameras (phase 3) and investigate their *social acceptability* in the field (phases 4+5). Most notably, my results show that bystanders' knowledge about usage intentions has an effect on social acceptability, and that candid form factors can leverage this effect to improve social acceptability.

Third, I critically reflect on the presented *HCD* process and the employed methods. I discuss which existing methods are suitable to inform the design of socially acceptable human-machine interfaces, and illustrate how empirical methods and artifact creation can be intertwined to design socially acceptable interfaces. Finally, I highlight directions for future work, as well as risks and challenges in designing for social acceptability. This work may serve as a reference for developers, engineers, designers and researchers with an interest in social acceptability and designing human-machine interfaces for social context.

Zusammenfassung

Körpergetragene Kameras (engl.: *body-worn cameras*) versprechen durch ihre breiten Einsatzmöglichkeiten, beispielsweise die der Objekterkennung, des Trackings und der visuellen Navigation, sowie der kreativen Nutzung zur persönlichen Entfaltung und der fotografischen Aufbewahrung von Erinnerungen, eine Vielzahl an Vorteilen. Gleichzeitig ist nicht nur die Aufnahme von Bildern, sondern auch das Erheben von Einwänden gegen das Fotografiertwerden, ein essentielles, modernes Recht eines und einer jeden. Daher sind Einwände und Datenschutzbedenken unbeteiligter Zuschauer im Hinblick auf die Kameranutzung schwerwiegend und legitim. In der Folge fehlt es heutigen körpergetragenen Kamerageräten meist an sozialer Akzeptanz: eine technologiegestützte Vermittlung in Interessenskonflikten zwischen Gerätenutzer und Zuschauern findet nicht statt. Die vorliegende Dissertation löst dieses Designproblem indem sie in der Gestaltung sozial akzeptabler körpergetragener Kameras sowohl die Bedürfnisse und Werte der Benutzer als auch die von umstehenden Personen berücksichtigt und im Rahmen eines nutzerzentrierten Designprozesses (engl.: *human-centered design, HCD*) adressiert.

Im nutzerzentrierten Design (HCD) sind Methoden und Lösungsansätze für die Gestaltung sozial akzeptabler Benutzungsschnittstellen nur spärlich etabliert. Insbesondere werden Akzeptanzprobleme häufig erst nach oder während der Markteinführung berücksichtigt, was die kostspielige Neugestaltung der Benutzungsschnittstelle, oder eine erhöhte Stigmatisierung der Nutzer zur Folge haben kann. Ausgehend körpergetragenen Kameras, untersuche ich, inwiefern Interface Design soziale Akzeptanz fördern kann, und wie soziale Akzeptanz als zentrales Designziel durchgängig in allen Phasen des HCD Prozesses integriert werden kann. Dazu trägt diese Dissertation folgendermaßen bei:

Im ersten Teil analysiere ich die aktuelle Forschungspraxis zum Thema soziale Akzeptanz in der Mensch-Maschine Interaktion. Ausgehend von einer strukturierten Literaturrecherche, lege ich detailliert dar, welche Methoden und Messgrößen, sowie Designstrategien Verwendung finden und wie diese zur Evaluation, Quantifizierung und Ausgestaltung von sozialer Akzeptanz eingesetzt werden. Meine Analyse zeigt insbesondere auf, dass die derzeitige Forschungspraxis eine unausgewogene Verteilung methodischer Ansätze und eine mangelnde Vernetzung empirischer und generativer Forschung.

Im Hauptteil untersuche ich, wie das Design von körpergetragener Kameras sowohl die Bedürfnisse, Ziele und Werte des Benutzers als auch die von unbeteiligten Zuschauern erfüllen kann. Jeder Phase eines exemplarischen HCD Prozess durchlaufend, untersuche ich die Haltung gegenüber körpergetragenen Kameras, sowie damit verbundene Sorgen und Erwartungen (Phase 1). Anschließend exploriere und diskutiere ich Designoptionen (Phase 2), sowie die prototypische Umsetzung intelligenter tragbare Kameras (Phase 3). Abschließend evaluiere ich die soziale Akzeptanz der erstellten Forschungsprototoypen im Feld

(Phase 4+5). Meine Ergebnisse zeigen, dass das Wissen das der Zuschauer über die Nutzungsintention des Kameraträgers hat, die soziale Akzeptanz beeinflusst, und dass Formfaktoren die solches Wissen vermitteln, die soziale Akzeptanz verbessern können.

Im dritten und letzten Teil reflektiere ich kritisch über den vorgestellten HCD Prozess und die eingesetzten Methoden. Ich diskutiere, welche der bestehenden Methoden geeignet sind, um sozial akzeptable Mensch-Maschine Schnittstellen zu gestalten und veranschauliche, wie empirische und generative Ansätze miteinander verknüpft werden können. Abschließend gehe ich auf zukünftige Forschungsansätze sowie die Risiken und die Herausforderungen bei der Gestaltung sozial akzeptabler Mensch-Maschine Schnittstellen ein. Diese Arbeit dient als ein Referenzpunkt für Entwickler, Ingenieure, Designer und Forscher mit Interesse an sozialer Akzeptanz und der Gestaltung von Mensch-Maschine Schnittstellen für die Nutzung in sozialem Kontext.

Contents

1 Introduction

Both taking pictures, and the option to consent or object to having one's picture taken, can be understood as essential, modern-day rights. On the one hand, there is a range of potential risks related to image or video data. Photographic imagery can harm personal privacy, or expose sensitive data (e.g., credentials or credit card numbers). In addition, the ubiquitous presence of cameras can – by contributing to so-called surveillance pressure – affect psyche and personal well-being: the awareness that one might be captured on video anytime and anywhere is unpleasant and disturbing for most people, especially if this happens without their knowledge or consent. On the other hand, both personal and professional picture taking have become nearly ubiquitous nowadays. For many, recording imagery in the context of sports and other leisure or family activities has become a non-negligible part of daily life; A treasured way to permanently capture memories. Photography has become essential to freedom of press and arts, and contributes to personal development and self-actualization: sharing personal images online, publicly in social networks, or privately in group messages has become essential to social life. Professionals, such as photographers, journalists, artists as well as bloggers or instagrammers rely on camera footage in terms of their occupation and income. In parallel, personal recordings can also serve to document processes, environments or objects, increase accountability, or anticipate uneven surveillance measures, as proposed by the sousveillance ("inverse surveillance") principle [Man04].

As a recent development, body-worn camera devices – well-known variants are Google Glass or the Narrative Clip (a so-called lifelogging camera) – have taken ubiquitous photography to the next level. Taking the step from being hand-held, e.g., as part of smart phones, to being worn, e.g., attached to clothing and accessories, brought a range of advantages: for example, cameras integrated in glasses can provide a stable, first-person perspective on the environment, allow hands-free picture-taking, and ensure good quality for continuous streams of images [WAS+15]. Moreover, the use of visual features (e.g., from a continuous camera feed) can enhance GPS tracking accuracy and enable detailed navigational instructions, even indoors [MKD+14]. The combination of a camera feed and artificial intelligence can create virtual assistants that can recognize persons, places and currency, read out signage, menus and other textual information, or describe scene contents. Simultaneously, body-worn camera devices have caused strong criticism and controversial discussions. Central point of criticism is their miniaturized and wearable form factor which causes the camera to be seemingly "always-on", and enables surreptitious photography. To bystanders it is often completely indiscernible what the respective device is technically capable of and how and to what extent it might record them. Denning et al. [DDK14] point out that the concerns about the current devices have a completely new quality, since they are more inconspicuous to use than conventional, hand-held cameras.

Figure 1.1: Ubiquitous photography. Snapshot illustrating the tension between restricted picture taking, and being recorded without consent: both taking pictures, and the option to object to having one's picture taken, can be understood as essential, modern-day rights. *Image taken 2019 at The Goat Farm Arts Center, Atlanta, GA, USA.*

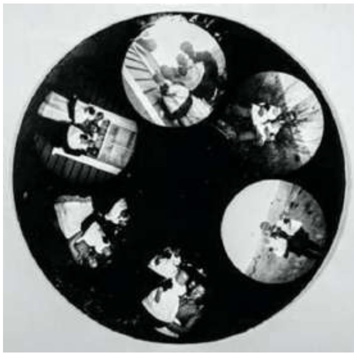
In addition, today's body-worn cameras are on the verge of becoming intelligent, autonomously acting devices that not only "see" their environment, but – being powered by artificial intelligence – also process and understand it. By incorporating artificial intelligence, cameras become opaque to users who do not know how the system was trained, do not understand its intentions and decisions. Instead they *"will develop a mental model that suits their folk theories about AI, and their trust will be affected"* [Lov18]. As a result, intelligent – or "smart" – body-worn cameras intensify social acceptability issues by disregarding human needs for transparency and explanation. To this end, the aim to design socially acceptable body-worn cameras also ties into the movement towards responsible artificial intelligence where interpretability, trust and accountability play an important role [SSW19].

In summary, body-worn camera technologies have enormous potential for a variety of applications (see also Section 1.2) that could have a positive impact on many aspects of our society – provided that the socially acceptable use can be made possible. At the moment, the strong social rejection of body-worn camera technologies causes wearers to face a field of tension between the non-use of technology – a potential restriction of their personal right to free development – and negative judgment by others, from criticism to stigmatization and exclusion. We therefore see the need to better understand concerns and fears associated with body-worn camera devices in order to develop appropriate technological solutions. This thesis addresses this need by *designing socially acceptable body-worn cameras.*

The focus of this thesis – social acceptability of body-worn cameras – falls into line with the shift in HCI towards emotions [BDD+07], experiences [Has08], values [BM12], and needs (so-called third wave HCI, c.f., Bødker [Flød06]). Social acceptability is an aspect of technology use that is often emotionally charged and shaped by societal needs and values. A lack of social acceptability can have a profound effect on the user's self- and external image, and affect the overall user experience, as it may include the risk of stigmatization, misperceptions and negative judgment through others. With this in mind it is surprising that the *socially acceptable design of human-computer interfaces* has been paid little attention so far. Most notably, social acceptability is often only considered in the beginning of a design process (requirements analysis), or at the very end (deployment/launch). With the work presented in this thesis we substantially contribute to establishing social acceptability as a core feature throughout the whole human-centered design process.

1.1 A Brief History of Body-worn Cameras

(a) 'CP Stirn's Patent Concealed Vest Camera' (1886-1896) in The Kodak Collection at the National Media Museum, Bradford



(b) Plate of developed images taken with the Stirn camera in the Otago Museum Collection.

Figure 1.2: 'Detective cameras', early wearables, such as Stirn's waistcoat camera, were marketed to take surrepitious images of bystanders[1].

[1] Images: (a) Science Museum Group Collection, taken from http://collection.sciencemuseum.org.uk/objects/co8204528/stirns-waistcoat-camera-and-neck-cord-waistcoat-camera-accessories, accessed 2019. (b) Otago Museum Collection by Jen Copedo, taken from https://otagomuseum.nz/blog/est-1868-stirns-optimus-detective-camera/, accessed 2019.

Between 1886 and 1888, approximately 15,000 examples of the Stirn brothers' patented waistcoat camera (see Figure 1.2) were sold under the name 'CP Stirn's Patent Concealed Vest Camera'. For their time, the waistcoat camera's form factor was dramatically diminutive, which promoted surreptitious photography and earned them the title "detective cameras" [Wal98]. In fact, during this late Victorian era, photography as such was highly controversial and *"provoked both intense fascination and intense discomfort"* [Men91]. This early success of a body-worn camera illustrates that both, the idea of wearable picture taking, as well as the associated concerns are much older than digital photography and wearable computing, which were only conceived around one hundred years later. Naturally, those early body-worn cameras were nothing more than picture taking devices operated through a button press. They did not possess any (built-in) intelligence or computing power. However, their size, form factors and looks were not dissimilar from early, camera-equipped wearable computers.

In the late 1900 and early 2000, researchers appreciated the opportunities arising from the integration of imaging sensors into various types of wearable computers. Early (bulky) prototypes of head-mounted computers, whose successors are today called smart glasses, made use of build-in cameras to track the user's environment (c.f., Mann et al. [Man97]), but also wearable cameras of other form factors were explored from early on. For example, wearable computing pioneer Steve Mann explored a chest-worn camera device (see Figure 1.3) to realize assistance by a remote user through laser-based projective Augmented Reality [Man00]. The chest-worn, 'dome' shaped device contained a computing unit and a laser-based infinite depth-of-focus projector (called 'aremac') combined by means of a beamsplitter to achieve a projection in the environment visible to the user. While still being relatively large and operated almost 'Wizard-of-Oz' style by the remote collaborator, the wearable 'Sixth Sense' camera illustrates an early vision of camera-based assistance in everyday use cases.

In the following years, multiple chest-worn cameras, namely the Microsoft Sensecam[3], the Vicon Revue (licensed version of the Sensecam) and the Autographer[4] became popular research vehicles (e.g., in work by Doherty et al [DPC+12], or Hodges et al. [HWB+06]). Those devices (illustrated in Figure 1.4) contained various sensing capabilities, including GPS, a accelerometer, sensors for light-intensity, light-color, temperature, and passive infrared that are monitored by a build-in microprocessor: if, for example, changes in light color and intensity are detected, a photograph is taken. Alternatively capturing might operate on a fixed interval, for example taking a picture every 30 seconds.

[2] Images: Steve Mann, taken from `https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/wearable-computing`, accessed 2019

[3] `https://www.microsoft.com/en-us/research/project/sensecam/`, accessed 2019

[4] As of 2019 the OMG Autographer's original webpresence, `http://autographer.com/`, had been discontinued. Wikipedia (`https://en.wikipedia.org/wiki/Autographer`) hosts a summary including a link to an archived version, accessed 2019

(a) Wearable camera device encapsulated by a 'dome'.

(b) The 'Sixth Sense' provides the user with in-situ assistance, e.g., during grocery picking.

Figure 1.3: 'Sixth Sense' camera[2]: a remote user views the images of a chest-worn webcam (left) and directs an 'aremac' laser projector to display information in the user's immediate surroundings (right).

Despite also being criticized for privacy issues [Pay13], Autographer and Sensecam were widely used in research. In contrast, most commercialization attempts of other body-worn camera devices targeting the consumers market struggled to gain momentum, as for example illustrated by Snap's Spectacles [Con17]. Nevertheless, there is a continuous stream of crowdfunding campaigns on platforms such as Indiegogo[5] and Kickstarter[6] competing for funds to realize body-worn camera devices of various shapes and sizes and for a multitude of usage scenarios. While I will not detail on the fundraisers themselves in this work, this range of products lively illustrates the wide range of form factors, shapes, and styles that are applicable to body-worn cameras: camera devices can be clipped to clothing (c.f., the Narrative Clip, Figure 1.5a), take the shape of accessories such as glasses (c.f., Snap's Spectacles, Figure 1.5b), headbands, neckbands, wristbands (c.f., Beoncam, Figure 1.5d), finger ringsor flexible forms (c.f., Flexcam Pic, Figure 1.5c). However, what can be observed is that compared to Mann's Sixth Sense camera, or even the Sensecam or Autographer, these devices seem relatively 'dumb': they act on a fixed time interval (Narrative Clip), on the user pressing a button (Snap's Spectacles, and Flexcam PIC) or are operated via a connected smart phone (Beoncam). It might even be debatable whether they could or should be considered "wearable computers", as in a (narrow) sense they would have to be *"something that the wearer can reconfigure, program, etc., while wearing it, as well*

[5] As of June 1st 2019, Indiegogo lists 22 (13 successful) "wearable camera" projects at `https://www.indiegogo.com/`.

[6] As of June 1st 2019, Kickstarter lists 30 (15 successful) "wearable camera" projects at `https://www.kickstarter.com/`.

Figure 1.4: Early prototype of the SenseCam [SFA+07]. Body-worn cameras have been successfully used as research vehicles: originally envisioned and prototyped by Lyndsay Williams as wearable accident recorder, the SenseCam became part of a dissemination initiative initiated by Steve Hodges that promoted the device for various research applications. According to Microsoft[3] the SenseCam was used in the creation of over 200 research papers.

as something that implements Humanistic Intelligence" [Man13]. Yet, they offer only limited intelligence and options for interaction. Most notably, their function range is similar to state-of-the-art DSLRs [7], which – intuitively – would not be considered body-worn cameras, even when carried on a strap.

In contrast, smart glasses, successors of Sutherland's early vision of a head-mounted display [Sut68], implement the concept of a head-worn wearable computer, while (some) almost resemble prescription glasses (see Figure 1.6a). Based on mobile operating systems, e.g., Android, many of them are able to connect to nearby devices or the Internet, and perform reasonably complex tasks, e.g., face and object recognition or tracking. Similarly, there are a few "clip-like" camera devices, such as Google Clips (c.f., Figure 1.6b) that employ artificial intelligence, e.g., to automatically snap 'memorable moments' [Lov18]. Just as not all available 'clips' are intelligent, not all available smart glasses are equipped with a built-in camera. Hence, some smart glasses devices, e.g., Focals by North[8] or Jins Meme[9], do not fall into the scope of this thesis. Instead, this work focuses on *smart glasses equipped with one or multiple cameras.*

1.2 Application Scenarios

In this section I outline a range of potential usage scenarios for body-worn camera devices. While some of the studies presented in this thesis (e.g., Section 3.1) verify that the intentions of use, and thus the concrete usage scenario, is relevant to social acceptability, I decided to not limited my work to a particular application

[7] DSLR, abbreviation for digital single-lens reflex cameras.
[8] `https://www.bynorth.com/focals`, accessed 2019
[9] `https://jins-meme.com/en/`, accessed 2019

(a) Narrative Clip: clipped to clothing or accessories

(b) Snap's Spectacles: worn as sun glasses

(c) PIC: reconfigurable, elastic neck.

(d) Beoncam: worn as wristband.

Figure 1.5: Commercially available, body-worn cameras come in a large range of different form factors, but most display only limited intelligence or interactivity: they take pictures based on a fixed time interval (a), a button press (b, c) or triggered via a connected smart phone (d).

area, or the usage scenarios presented in this section. Instead, this section should provide a glimpse of options that state-of-the-art research provides today, and might be possible in the future. In addition to applications of body-worn cameras, I also present a number of camera-based applications available on today's smart phones that could - in the near future - be no longer hand-held, but implemented for wearable cameras. Rather than providing a complete view of the (ever-growing) number of application areas, this section aims to supplement and contextualize the design considerations presented in this work.

Personal Expression and Memory Keeping

Cameras of various kinds facilitate the collection of personal episodic memories. Cameras that are attached to the body or placed in the environment free the hands for other activities than picture taking. Particularly for recording sports, so-called "action-cams", body-mounted video-cameras like the Go-Pro [10], have become tools for hands-free capturing of experiences, and experience sharing. With various forms of video lifestreaming gaining popularity, the increasing

[10] GoPro, `https://gopro.com`, accessed 2019

(a) Google Glass

(b) Google Clips [Lov18]

Figure 1.6: Body-worn camera devices implementing artificial intelligence. Smart glasses devices (a) have already undergone rapid miniaturization, and might come close to prescription glasses in the near future. Clip-like devices (b) could be worn, and attached to household items, or even pets.

wearability of cameras enabled new forms of self expression. Users more and more appropriate the content and topics to exceed the traditional formats of face-to-face video calls by jointly engaging in activities over extended periods of time [NG12]. Some wearable camera devices, e.g., Snap's Spectacles[11], explicitly aim for users who aim to record and share images for personal expression (see Figure 1.7 for examples). The FrontRow camera[12] which features a front, and a back camera, is one further example, designed to enable sharing both, the wearer's surroundings, and their facial expressions. Lottridge et al. [LBW+17] report teens to utilize video lifestreaming as "long form selfie" to socialize with friends including structured activities such as verbal games, or by streaming art or DIY projects. This way to "co-experience" daily activities has been shown to increase intimacy in long-distance relationships [NG12]. In-time video sharing during marathon events can increase runners' motivation and audience engagement [AKE16].

Experience Sampling and Documentation

In addition to personal expression and memory keeping, body-worn cameras have been used for research and documentation; for instance, to capture first-person perspectives of mobile phone users in the field [PPH+11], as shown in Figure 1.8. The reminiscing effect of reviewing lifelogging imagery has also been successfully used as a method to foster creativity in participatory user-experience

[11] Snap's Spectacles, https://www.spectacles.com/, accessed 2019
[12] FrontRow camera and video archive, https://www.frontrow.com/works/, accessed 2019
[13] Images: Snap, Inc., Screen shots taken from example videos at https://www.spectacles.com/de/perspectives, accessed 2019

Figure 1.7: Promotional "perspectives" (first-person video) on Snap's web site[13] illustrate how the company envisions hand-free photography for personal expression and as part of lifestyle activities.

research [ABW17]. Moreover, when introduced as a reliable, visual sensor for data collection wearable cameras resolve the issue of discrepancies between the study participants' self-reported behavior and their actual behavior(c.f., Harvey et al. [HCS15]). This method has been successfully employed in areas such as health documentation [HSC16], as well as in personality and social psychological research [BBS17].

Similar to CCTV[14], body-worn cameras are also valued for evidence keeping, e.g., in situations, where a safety-relevant unexpected event, such as a break in, accident, or assault might occur [WSB+14]. In these contexts body-worn cameras have the potential to increase accountability, an effect which has been widely studied in the context of police work, where body-worn cameras have been employed both for evidence keeping and as a tool for deescalation: Researchers were able to show that body-worn cameras are able to reduce response-to-resistance incidents and external complaints [ASH+17; JLF15] resulting from officer non-compliance with procedures, and suspects' demeanor, as well as reduce "vexatious complaints". Ariel et al. [ASH+17] conclude that, in fact, body-worn cameras can be construed as a "fix" in terms of police accountability.

Figure 1.8: Body-worn cameras allow to capture first-person perspectives during field studies[15]; here: navigating Oldenburg's city center.

[14] CCTV, abbreviation for closed-circuit television, commonly known as video surveillance.
[15] Images: Benjamin Poppinga, ca. 2012.

Assisting in Everyday Live

When Thad Starner presented his early vision of Augmented Reality (AR) in 1997, he envisioned a wearable and intelligent assistant for every day life that observes the user's context through a body-worn camera and consistently, and continuously adapts to it. Among the early concepts were, for instance, a remembrance agent to help with personal organization, or an interpreter for American Sign Language (ASL) to help with communication [SMR+97; SWP98]. Since then, body-worn cameras or camera-equipped smart glasses have been explored as assistive devices for these and numerous other use cases. Camera-based assistance for users with visual impairments had been explored in academic research [ZSA15; RRC+17; SFF18; ZWR+18], but also made its way to the consumer market as part of Microsoft's Seeing AI[16]: intelligent assistants already can recognize persons, places and currency, read out signage, menus and other textual information, and even describe scene contents based on image classification (see Figure 1.9, left). Google Lens[17] targets a broader audience and provides object recognition, text and character recognition for instant search, and in-situ translation (Figure 1.9, right), e.g., for tourists. Ruffieux et al. [RRC+17] explored smart glasses as visual prostheses for face and emotion identification, to aid patients with low vision, dementia, and mental disorders. Moreover, camera-equipped smart glasses have been tested to assist patients with Parkinsons [MVR+14], amnesia [KB14; PME11] or autism [KG15; WWV+17]. Although the tested research prototypes did not yet make their way out of the labs, overall results were confident, and might soon allow to make real-life easier for patients. Outside of clinical contexts, researchers investigated the use of body-worn cameras for memory augmentation, particularly as retrospective memory aid [HWB+06; HSC16; DPC+12], and to assist with language learning [HOK+13] or with keeping track of dietary behavior [ASV+18; OCM+13].

Enabling In-situ Information Access

Mobile cameras can be useful wherever the user needs to map digital information to her physical environment. This might include navigating an unknown location: by identifying visual landmarks from a mobile camera's imagery (e.g., Chen et al. [CBK+11]), not only the user's position, but also her viewing angle can be determined, and navigation hints can be adjusted to her needs. Considering localization and navigation, image-based approaches are particularly advantageous, where other types of positioning are failing, such as GPS does indoors, or when costly infrastructure, e.g., for WLAN fingerprinting, would have to be established and maintained. Knowledge about the user's view of the world also allows to display an Augmented Reality navigation overlay that is spatially registered with the real environment (c.f., Figure 1.10) and can e.g., improve navigation

[16] `https://www.microsoft.com/en-us/ai/seeing-ai`, accessed 2019
[17] `https://lens.google.com/`, accessed 2019

(a) The banknote's value is visually detected, and provided to the user as audio output: "Five Canadian Dollars".

(b) The menu's text is detected from the camera's image. Its translation is then superimposed on the original frame. *Image taken 2019 at Käthe Kaffee Oldenburg, Germany.*

Figure 1.9: State-of-the-art intelligent assistants can utilize a camera's view (here: a smart phone's camera) to assist visually impaired user's in recognizing currency (Microsoft SeeingAI left), or to provide in-situ translation, e.g., for tourists (right).

performance [MKD+14; NPF+06]. While it is practical to have both hands free during navigation, tasks in different working scenarios might even require both hands to be available. In these contexts, smart glasses can enable hands-free human-machine interaction and information access, and – when a camera is used as basis for an optical tracking system – a spatially registered integration of digital information and physical objects. Augmenting the user's view of her work space has been explored as a tool for "Industry 4.0", where instructions for unfamiliar tasks (e.g., assembly of new products) are registered in 3D and superimposed on the current work piece [Pae14]. All these use cases, particularly correct three-dimensional registration, only become possible through visual tracking, i.e., they require a camera, that, in return, may be subject to objections. While up to today Augmented Reality was often limited to a "Wow Effect" [DGS+07], and productive, industrial applications were still in the fledgling stage, we are (almost) ready to move beyond pilot stage: recently, DHL established the use of smart glasses for warehouse logistics, particularly vision picking, and noted increased productivity and accuracy[18].

(a) Google Maps' AR Mode (Beta) in Hannover, Conrad-Wilhelm-Hase-Platz.

(b) Screenshot of the Maps interface in Munich.

Figure 1.10: Augmented Reality (AR) applications often rely on a camera stream for tracking the environment. AR navigation overlays (here: Google Maps Beta) that are spatially registered with the real environment help the user's sense of orientation and can improve navigation performance.

[18] DHL Press Release, 26.01.2015, `https://www.dhl.com/en/press/releases/releases_2015/logistics/dhl_successfully_tests_augmented_reality_application_in_warehouse.html`, accessed 2019

1.3 Legal Background

Body-worn cameras trigger concerns about unintentional, unwanted and surreptitious photography. As a result, potential privacy infringements of bystanders such as conversation partners, spectators or passers-by are often named as central social acceptability issue with body-worn cameras. In addition, there is a strong conceptual connection between privacy, discretion and impression management, which affects social acceptability (discussed in Section 2.2). In consequence, the legal framing for body-worn cameras is mostly rooted in privacy legislation. In this section I briefly outline the legal background for body-worn cameras, with a particular focus on privacy legislation in Germany, the country where many of the user studies presented in this dissertation were conducted.

Privacy Legislation

In 1890, Warren and Brandeis conceptualized privacy as a state of psychiological security that can be distorted or injured when information about a person's "private life, habits, acts and relations" becomes available to others. Although the term privacy, as well as the idea of "a right to privacy" dated back to much earlier, the authors laid the foundation for the placement of privacy as an inherent individual right in modern legislation [Gla79]. Consequently, privacy, which had so far been undertheorized, but present in common law, quickly became an essential component of human rights law and theories. In the context of photography, first accounts for individuals' privacy, or "the right to one's own image", appear concurrently with the advent of personal photography, e.g., as early as 1907 in the German Art Copyright Act (KUG) [Sch16]. Nevertheless, with the first data protection laws dating back to the 1970s, e.g., the US Privacy Act (1974), or Hessen's Data Protection Act of 1970, privacy legislation can still be considered a relatively novel and, more importantly, continuously evolving concept.

In October 1995, the EU Data Protection Directive 95/46/EC was passed. According to this Directive, both still and moving images are considered personal data, and thereby protected, as they can potentially serve to identify a depicted person. Excluded from protection were purely personal or household activities, as outlined in Article 3(2) Directive 95/46/EC. More than twenty years later, however, even within EU member states, the legislation concerning photo- and videography still largely varies . This is not surprising, as legislatives are facing the challenge to balance reasonable individual intentions (e.g., artistic interest) with data protection, including questions such as "Did the subject consent to being photographed?", or "What is the audience of the recorded imagery?". While (in theory) many countries do allow unlimited picture taking for personal consumption, such as for showing photos to friends and family, others are more restrictive: in Italy, Denmark, or Finland no consent would be required to photograph public scenes (e.g., as a tourist) where passers-by are incidentally captured, whereas taking the same picture would be illegal in Spain or Switzerland. In May 2018 the

GDPR replaced Directive 95/46/EC aiming at a more coherent data protection framework in the EU. But explicit provisions concerning photo- and videography were not included. Therefore, there is a broad discussion on which impact the GDPR shall have on national photo law. Partly it is argued that opening clauses like Article 85 GDPR guarantee that the national photo law remains unaffected by the GDPR [LH17]. Others share the opinion that national provisions of photo and video law, like those in Germany, fulfill the requirements of article 6 (1) (f) GDPR anyway [Hoe18]. In consequence, privacy is, while accepted as nonnegotiable human right (Article 8 of the European Convention on Human Rights, ECHR), still in a state of continuous evolution and, with new challenges (such as wearable cameras) arising, recurrent negotiation.

Unwanted Photography

While audio recordings without consent are socially unacceptable and typically penalized, (e.g., in the US Wiretapping Law, or Para. 201 German Criminal Code), in terms of photography without explicit consent, legal regulations become highly complex and – not only to the eye of the layperson – fuzzy and confusing. Jurisdiction in the context of un-wanted photography typically comes down to weighing competing interests [Kla12]. In addition to everyone's right to privacy and the right to informational self-determination, German law also knows the statutory "right to one's own image" (Para. 22 KUG). This principle says that any picture of a person, where (s)he is not just an insignificant and coincidental element (so-called "Beiwerk", Para. 23 KUG), or part of a public gathering, may not be published, distributed or put on display without the consent of the depicted person. In case law, the "right to one's own image" is increasingly recognised not merely for publishing, but already for picture taking [Ros17]. A balancing of interests must be carried out by the German courts [Wan17]. To allow freedom of the press and opinion, an exception applies to pictures showing persons of public interest. Furthermore, German legislation excludes artistic interests (so-called "Höhere Interessen der Kunst"), i.e., photographs that are published as fine art, from the obligation to acquire consent, which is based on the idea of an individual's freedom of art. This conflict is characteristic for contemporary regulations in many regions: in each individual case, US jurisdiction has to balance the photographer's First Amendment freedom of expression against another person's right to privacy; the European Convention on Human Rights requires weighing its Article 8 (Privacy) and its Article 10 (Expression), e.g., ECHR in Lillo-Stenberg vs. Norway, 16.01.2014, NJW 2014, 3291.

Wearing a Camera in Public

While German law permits – to some uncertain extent – taking and sharing of photos showing individuals, at least for personal usage, another problem of body-worn cameras is gaining attention: the sole presence of a device with potential recording capabilities is perceived as a threat, even if the camera is turned off. Euler et al. [ECK17] found their interviewees to frequently compare body-worn cameras and camera-equipped drones to weapons, demanding regulatory interventions. Consequently, users are faced with the question of whether to wear a hidden or an openly visible camera. There is no legal provision in Germany which explicitly prohibit secret photography of persons, e.g., with a hidden body-worn camera. But if the taking of a certain photograph violates personality rights for other reasons, the interference is considered more serious if this photo was taken secretly [Ros17]. In video surveillance law, a notification to passers-by of being filmed is mandatory (see: Para. 4 German Data Protection Act). As of 2019, single photos or videos are permitted without making sure that anybody is informed of being in the picture. The unresolved question is therefore whether an intensive use of body-worn cameras equals video surveillance, in which case that notification to all depicted persons would be required. However, using an openly visible body-worn camera may also be a problem, even if it takes no pictures at all. Without the traditional gesture of photographing or equivalent signals, a special situation occurs called surveillance-pressure ("Überwachungsdruck") [Sch16]. Various German courts have regarded surveillance-pressure as a violation of the general right of personality, e.g., even in cases where camera dummys were used [Ros17].

Taking Multitudinous Pictures

There is a historical particularity to copyright law as it applies to photography: since the time of the inception of photography, in addition to photographic works (artistic photography exceeding a particular threshold of originality), also simple photographs (e.g., satellite or surveillance footage) are copyright protected, regardless of its depicted content or aesthetic value. In consequence, also incidental photography (like a pocket snap) are under copyright protection. Wearble cameras, such as e.g., life logging clips, carry this regulation ad absurdum: due to their "always-on" nature, they may produce an incredibly high amount of images, often without explicit effort on the user's part (e.g., snapping one picture every 30 seconds). Consequently, the camera wearer might hold copyright in images they are not even aware of. On the other hand, taken pictures may also infringe the copyright of other persons if, for instance, a piece of art temporarily displayed in open space is captured by the camera without the consent of the artist, see: Para. 59 German Copyright Act [Wan17]. A resulting question is to what extend a wearer of a smart camera should be (or would want to be) held accountable for what is being captured. As content and composition of the lifelogging images are often at random, persons might be unknowingly and incidentally depicted, but, e.g., when engaging in a conversation with the camera wearer, still be a central element of the resulting image. In consequence, the image would be perpetrating Para. 22 KUG (the "right to one's own image") when shared without consent. For this reason, sharing mechanism that do not require the wearer to conscientiously review the captured footage, e.g., by enabling automatic sharing, run the risk of privacy infringement and unintentional disclosure of sensitive information, so-called misclosures [Cai09].

1.4 Scope of the Thesis

The motivation of this thesis are potential benefits through body-worn camera devices that are 'smart', i.e., that do posses some humanistic intelligence and can perform tasks, such as activity or environment tracking or object recognition. Nevertheless, many of the results presented in this thesis are also applicable to devices that are wearable, but only body-worn picture taking devices acting on manual commands, e.g., Snap's Spectacles. The design approaches chosen in this work reflect this. For example, the co-design sessions, presented in Section 4.3, were not limited to a specific device type or form factor. Instead, participants were instructed to use a top-down approach, starting with concrete applications or use cases, and then elaborating on form factors and designs implementing those [KWB18]. Thus, the thesis title, "Designing Socially Acceptable Body-worn Cameras", omits 'smart' as defining term, and is deliberately held broad.

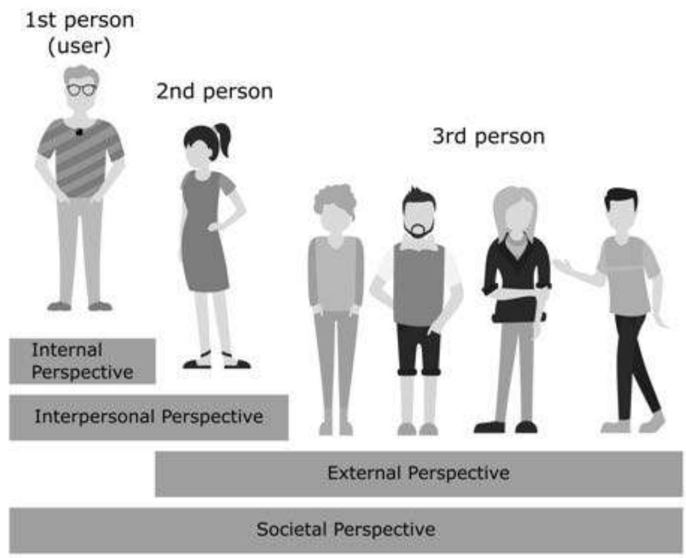


Figure 1.11: Different views and perspectives on the usage of technology in social contexts. We include both, an internal (user's) perspective, and an external (bystander's) perspective. We furthermore take into account interpersonal aspects, when user and bystander are interacting, e.g., when conversing, and a more macrosocial, *societal perspective.*

Traditionally, HCI mostly focused on the user's internal perspective, or interpersonal relationships between multiple users, e.g., computer supported collaborative work, CSCW. In contrast, this thesis focuses on *technology usage of individuals (1st person view, user)* in social context. We consider non-collaborative scenarios, where bystanders interacting with the user (2nd person view) or in their vicinity, but not interacting (3rd person view) are affected by the presence of the body-worn camera device. We illustrate different roles and perspectives in Figure 1.11. In practice, one person might unite multiple roles at the same time or switch roles when entering a conversation or donning a device. For example, it is sensible to imagine that a bystander to smart glasses might be wearing smart glasses (or any other wearable camera device) themselves. By adding a *societal perspective* we furthermore include macrosocial aspects beyond the individual user – bystander relationship, e.g., camera presence leading to *surveillance pressure*.

While privacy legislation (c.f., Section 1.3) comprehensively covers the publication of images interfering with a depicted persons personal privacy, camera presence as such, or camera-devices that do not persistently store data, are only sparsely covered and widely unregulated. The work presented in this thesis primarily focuses on this unregulated areas, and the affiliated user and bystander concerns and needs, such as justification and situation awareness (c.f., Section 4.3). In particular, it contributes design strategies to counteract perceived "surveillance-pressure" and technical solutions to mediate between users and bystander, instead of making suggestions for legal regulations or frameworks (as e.g., discussed in Euler et al. [ECK17]). In addition, privacy legislation primarily attends to cases where one legal entities privacy is affected by another legal entities action or omission, i.e., where a bystander's privacy is at risk because of the user wearing a camera. Other aspects of social acceptability or impression management (see Section 2), e.g., information about the user that might (unintentionally) be revealed through device usage, are mostly beyond the scope of legislation. The work presented in this thesis *explicitly covers both the user's and the bystander's needs*, e.g., in terms of privacy protection. For example, the prototype presented in Section 5.2, PrivacEye, implements this by attending to both the user's and the bystander's needs for privacy, by protecting *privacy sensitive situations* such as credit card usage (user privacy) and conversations (bystander privacy).

1.5 Research Questions and Contributions

Issues with social acceptability are not unique to body-worn cameras. Yet, the research field of Human-Computer Interaction (HCI) does not provide an established definition or framework of methods to address social acceptability. In fact, *social acceptability* is "rarely, if ever" defined [MAM+10]. Thus, I start by providing an overview of the current understanding of *social acceptability in HCI* (RQ0) and a working definition for the scope of this thesis.

> **RQ0:** How is social acceptability understood in Human-Computer Interaction?

Issues with social acceptability are often only discovered late in the development process, or on market entry, because social acceptability is often not considered throughout the entire design process. Thus, my dissertation discusses the question "How can we design with social acceptability in mind?" using body-worn cameras as example. In particular, it challenges interface design to attend to social acceptability issues not after deployment, but during all phases of the Human Centered Design (HCD) Process. I envision design and evaluation methods that do not only describe or verify social acceptability, but that drive the design of socially acceptable interfaces. To provide a broader theoretical foundation, I take an inventory of current practices for studying and addressing social acceptability issues in HCI. This approach allows to identify gaps in the distribution of current research approaches, shortcomings in the way research is conducted, but also best practices and options to be then explored in the context of body-worn cameras. Hence, the first goal of this thesis is to map existing practices by answering RQ1.

> **RQ1:** Which methods, measures and design strategies are employed to evaluate, quantify, and influence the social acceptability of human-machine interfaces?

Contributions: with this work I provide a systematic literature review of social acceptability in Human-Computer Interaction (HCI) and make the following three contributions: First, I analyze how the social acceptability of interactive systems has been evaluated in HCI. I outline and discuss methods and measures in terms of replicability, internal, external and ecological validity. Second, I provide an overview of design strategies that have been employed to increase the social acceptability of interactive systems, and discuss to what extend they have been verified by prior work. Third, I identify research gaps concerning social acceptability in HCI, and discuss challenges and opportunities to guide future research in this area.

Body-worn cameras have displayed a lack of social acceptability, e.g., due to concerns about bystander privacy. On the other hand, they also provide promising technological opportunities that could increase health, comfort and wellbeing and contribute to equal opportunities, and social empowerment. In this context, "designing for social acceptability" can be understood as the design of compromises between the users and bystanders. Thus, the main part of this thesis aims to explore this design challenge, both empirically and technically, or in other words to address RQ2:

> **RQ2:** How can we meet both the user's and the bystander's needs, goals, and values while designing socially acceptable body-worn cameras?

Contributions: The research presented in the main part of this thesis iteratively evolves design suggestions for socially acceptable body worn cameras following a HCD process. To better understand user (and bystander) requirements, this work contributes an analysis of user and bystander attitudes and expectations and identifies factors influencing social acceptability, namely context, bystander control, and knowledge about recording status and usage intentions. In addition, these factors are observed over time and contextualized and discussed in light of technology adoption. Design strategies leveraging these factors are then conceptualized through participatory design. More specifically, I present insights about suitability and choice of gestural Opt-in and Opt-out controls and an analysis of design strategies for status indicators concluding with 3 design recommendations for privacy notices of body worn cameras. Subsequently, I introduce and discuss different prototyping techniques for smart wearable cameras and present a proof-of-concept prototype of eye-tracking based, privacy-preserving smart glasses featuring a mechanical shutter. Evaluations through user studies in lab and field then verify the effect of these design strategies on social acceptability. A discussion of results obtained from evaluating research prototypes in relation to self-reports from users of off-the-shelf, body-worn camera devices, further contributes to a deeper understanding of how design aspects, form factors, and wearing styles can influence social acceptability issues with body-worn cameras.

The third objective of this thesis is to address the need for methodical best practices and suitable tools to design for social acceptability, which is addressed in RQ3:

> **RQ3:** Which methods are suitable to inform the design of socially acceptable human-machine interfaces?

Contributions: To explore RQ3, I discuss the selection of methods that has been applied during the presented human-centered design process. I summarize the methods under four main themes, namely (1) how to determine which design factors affect social acceptability, (2) how to make design choices accessible during participatory design, (3) how to facilitate the innovation of form factors, and (4) how to evaluate social acceptability in lab and field. I highlight potential pitfalls and possible alternatives, and discuss advantages and disadvantages of the presented methods. In summary, this discussion provides a "toolbox" for researchers, designers and engineers to chose suitable methods for designing socially acceptable human-machine interfaces.

1.6 Thesis Outline

This thesis is organized such that **Chapter 1** provides motivation and context, and **Chapter 2** and **7** surround an exemplary human-centered design process (**Chapters 3 to 6**). **Chapter 2** analyzes related work on social acceptability, and detail the methodical approach, human-centered design (HCD), used in this thesis. **Chapter 7** reflects on the employed HCD process and methods, and discusses risks and challenges in designing for social acceptability. The framed four chapters, **Chapters 3 to 6**, present research conducted as part of this HCD process; illustrated in Figure 1.12. While each chapter builds on the previous ones, they may also be read independently, and in an order free of choice. As the HCD processes is iterative by nature, phases may overlap, and results from later phases can, and are meant to, feed back into earlier phases, just as earlier phases should provide rationales for research conducted as part of the subsequent phases. Thus, while I opted to present Section 6.2, a study on usage of a deployed, off-the-shelf body-worn camera device, last and as part of HCD's *Implement & Deploy* phase, the study could also serve to *Observe & Understand* usage behavior, thus as a starting point for a new cycle, which I will discuss as directions for future work.

Chapter 2 *provides a theoretical and methodical background*. It first presents a *structured literature analysis* investigating the current practice of addressing social acceptability in HCI in terms of methods, measures and design strategies. The analysis verifies that the consideration of social acceptability issues is not established in all phases of the HCD process, and that design-oriented and participatory approaches are only sparsely applied. The second part covers the approach taken by this thesis to explore those methodical gaps, and towards designing socially acceptable body-worn cameras. The goals of this section are to provide sound theoretical foundations, as well as the rationales behind the methods used during the presented HCD process. The structured literature analysis was published at CHI 2020 [KAB20] and recognized with a CHI 2020 Honorable Mention Award.

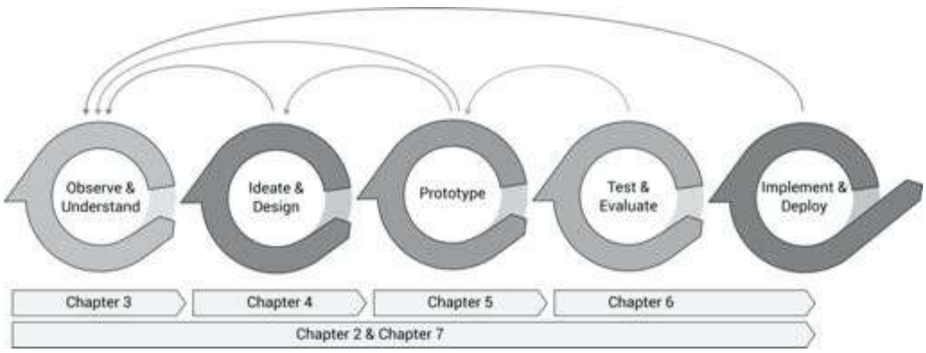


Figure 1.12: The four main chapters are structured along the Human-centered Design process (to be read from left to right). Earlier phases provide rationales for research conducted as part of the subsequent phases, which, in return, iteratively feed back into earlier phases. Chapter 2 and 7 provide background and reflect on the process as a whole.

Chapter 3 *investigates factors that cause a lack of social acceptability* in smart glasses. More specifically, it presents results of a focus group discussion that identifies controversial usage scenarios and applications, and a lab survey that confirms recording capability, perspective and communication of usage intention as factors influencing user attitudes towards smart glasses. Parts of this research, which I conducted at the University of Passau, has been published at MobileHCI

2015 [KKM15]. The chapter furthermore presents results from a follow-up case study, where the original lab survey (2014) was repeated twice (2015, 2016), at intervals of one year each, and contextualized based on an online survey among experts. Parts of this section have been published at CHI 2017 [KEC+17]. Both works inspired the thematic alignment of my research and motivated a focus shift from smart glasses to body-worn cameras of various form factors. After all, the factors identified by the studies as contributing to a lack of social acceptability, namely unknown intention of use and recording status, as well as concerns about bystander privacy, are shared by all types of body-worn (in contrast to hand-held) camera devices, not only by smart glasses. The expert study comprised by the latter paper, and embedded in the BMBF project ChaRiSma[19] at the University of Oldenburg, deepened and largely shaped the methodical research questions addressed by this thesis. Most importantly, it pinpointed the question *"Is it possible to design for social acceptability?"*.

Chapter 4 *explores design options for socially acceptable body-worn cameras* with regard to bystander control (Section 4.2) and privacy notices (Section 4.3). While the former focuses on gestural controls for bystanders independent of camera properties, the latter purposefully considers a wide range of application areas and form factors, including chest-, and head-mounted cameras (smart glasses), and shoe-worn devices. The section contributes insights about choice and suitability of gestural Opt-in and Opt-out controls as well as design recommendations for privacy notices. Large portions of this chapter are based on work published at NordiCHI 2018 [KAC+18] and TEI 2018 [KWB18]. The latter work was awarded the TEI 2018 Best Paper Award.

Chapter 5 *explores prototypes of body-worn cameras.* It begins by discussing challenges in building "smart" wearable cameras and contributes an annotated portfolio of research prototypes that are evaluated and discussed with regard to wearablility, realism, functionality and fidelity. While Section 5.1 focuses on multiple different prototyping approaches and form factors, Section 5.2 leverages a smart glasses form factor into one research prototype: PrivacEye. It presents a proof-of-concept implementation of eye tracking based, automatic de- and re-activation of a head-worn camera featuring a mechanical shutter. This work demonstrates how devices with integrated cameras might react proactively to context and communicate the camera status to bystanders. Furthermore, a series of interviews provides insights about user perception of such proactive privacy-protection. The idea for PrivacEye originated during a winter school at Söllerhaus[20]. Dissatisfied with the prospects of audio-based or manual camera de- and re-activation, I approached Julian Steil, who - during this winter school - had presented his PhD research on activity recognition based on eye-movement data, with the idea of exploring egocentric eye tracking to gauge privacy-sensitivity. The

[19] BMBF project ChaRiSma, `http://www.charisma-projekt.de/`, accessed 2019
[20] Winter School on Human Computer Interaction in the Age of Artificial Intelligence, `https://www.hcilab.org/winterschool/`, accessed 2019

result was PrivacEye, a joint work with MPI Saarbrücken and the University of Stuttgart. I am greatful for the experience of this eye-opening collaboration, where my co-author Julian contributed a pre-exisitng data set [SMS+18], PrivacEye's classification approach, technical evaluation and quantitative analysis, and I contributed idea, design rationale and interaction design, hardware prototype and demo video, as well as the interviews' qualitative analysis. PrivacEye's final concept, the annotation scheme, study design, procedure and questionnaires for both studies as well as interpretation and discussion of the results were joint efforts of all co-authors. Parts of this work have been published at ETRA 2019 [SKH+19] and showcased in the Video & Demo Session at the same venue. The work received the ETRA 2019 Best Demo/Video Award.

Chapter 6 *focuses on body-worn cameras in real-life contexts.* Each of its two sections presents one user study. The first study (Section 6.1) evaluates a research prototype, a wearable camera with an integrated display. In addition to an assessment of bystander reactions to screen-based status indicators, the presented field survey contributes insights about evaluations of social acceptability in-the-wild. This section is an extended version of work published in CHI 2019 Extended Abstracts [KWH+19]. Section 6.2 looks into deployed, off-the shelf devices and presents an online survey investigating usage behavior of lifelogging camera wearers. This work contributes insights about hidden, unobtrusive and candid wearing styles of lifelogging cameras in everyday life. Part of it has been previously published at MobileHCI 2017 [KHB17].

Chapter 7 completes the discussion of design strategies (Section 7.1), and methods (Section 7.2) for creating socially acceptable body-worn cameras using a human-centered design approach. Finally, I conclude this thesis by outlining challenges for future work.

The research conducted in the context of this dissertation has been comprehensively published in highly selective, peer-reviewed outlets, and presented at renowned international venues. I list the individual publications in Appendix A.

Just like any research, the research presented in this thesis could not have been conducted in isolation. Conversations and discussions with my colleagues and project partners, as well as numerous researchers and practitioners at conferences, workshops, and during lab visits shaped the way I viewed and set my research goals, build my prototypes, and chose my evaluation methods. In the context of this work, I also co-supervised several Bachelor and Master theses, and students' research projects that served as starting points for work described in this thesis, including [Czu17], [MSK+18], [Web19], and [Mey19]. For these reasons, I chose to write the remainder of this thesis using the scientific plural.

2 Social Acceptability in HCI

The study of context, including *social context* has a long tradition in HCI. In 1999, Schmidt et al. [SBG99] specified the user's *social environment* which might comprise features such as the co-location of others, social interaction, or group dynamics as essential (human) factor of context. Nevertheless, in the last two decades research on context-aware (mobile) interfaces majorly focused on context based on the user's *physical environment*. In comparison, *social context*, specifically *social acceptability* is less well explored, and less well defined.

This chapter covers how *social acceptability* is and can be approached from an HCI perspective. First, we review how social acceptability is understood and defined in HCI, and provide a working definition. Second, we take an inventory of current practices for studying and addressing social acceptability issues in HCI. This allows to map established methods, identify shortcomings in the way research is conducted, and propose opportunities for future approaches. Finally, we provide a methodical perspective on how this thesis approaches social acceptability issues with body-worn cameras through a human-centered design process and how its approach and method complement existing practices.

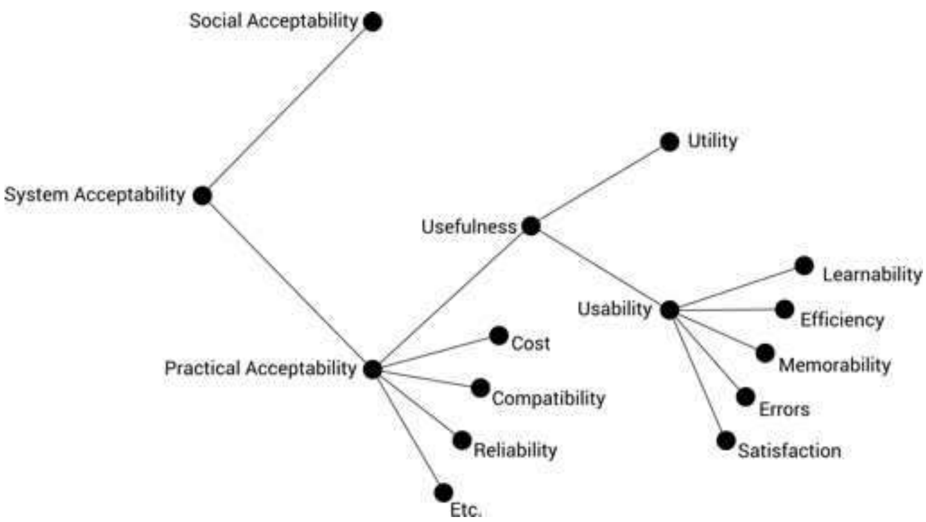


Figure 2.1: Nielsen's taxonomy of system acceptability [Nie94]. Social acceptability can be found at the top left. In comparison to *practical acceptability* (e.g., usability), *social acceptability* is still underexplored.

2.1 Background and Definition

The notion of *social acceptability* is not new to HCI. In 1994, Nielsen named social acceptability as essential part of system acceptability [Nie94], c.f. Figure 2.1.

Despite this, HCI research until today mainly focused on creating and improving what Nielsen embraced as practical acceptability, including e.g., usability, and utility: the *social acceptability* of human-machine interactions is an underexplored, and underdefined area. The terms *social acceptability* and *social acceptance* are difficult to grasp, as they – albeit being frequently named as user requirement – are not always clearly defined [MAM+10]. In addition, there seems to be a considerable overlap with concepts such as *social weight* [HSP+08; TMT+03], *social comfort* [DPZ+14] or *social wearability* [DPZ+14].Montero et al. highlight that a lack of a clear understanding can be a hindrance in creating socially acceptable interaction techniques [MAM+10]. They also note how social acceptance and user acceptance as comprised by the Technology Acceptance Model (TAM, c.f., Davis [Dav86]) are not always clearly differentiated, and often confused.

With this section, we disentangle those overlapping and related concepts, and provide a concise *working definition of social acceptability* for the scope of this thesis. We investigate the research question

> **RQ0:** How is social acceptability understood in Human-Computer Interaction?

and, aggregating accounts from prior work, model the social acceptability of a human-machine interaction as a process of impression management. We furthermore outline the interplay between *social acceptability* and privacy, and relate it to the technology acceptance model (TAM).

A Definition by Negation

In a specialist dictionary (c.f., APA Dictionary of Psychology [Van07]) issued by the American Psychological Association (APA) *social acceptance* is defined as a two-fold concept:

> social acceptance
>
> 1. the formal or informal admission of an individual into a group.
> 2. the absence of social disapproval.
>
> APA Dictionary of Psychology[1]

This definition **by negation** (as in 2.) is also common in HCI, where *social acceptability* often defined through its absence: *"A socially acceptable wearable is most notably marked by an absence of negative reactions or judgments from others."* [KG16]. In an earlier work, Toney et al. define the social weight of a human-machine interaction as the *"measure of the degradation of social interaction that occurs between the user and other people caused by the use of that item of technology"* [TMT+03]. Both describe *social acceptability* not only by negation, but also as a reciprocal rather than an isolated, individual experience. We discuss this duality between user (performer) and others in their vicinity (spectators) in the following. We back this discussion using a well-established concept from sociology, Goffman's theory of impression management [Gof59].

Duality: Performer and Spectator

Following Goffman's basic premise that all public action is a performance [Gof59], and that performances are typically staged for an audience, it seems self-evident that also human-machine interactions can involve both, *performer* and *spectator*. As an individual will strive to control and consciously shape the impression other persons will form of them, this duality of performer/spectator roles influences *if, how and where human-machine interfaces will be used.* First highlighted by Brewster et al. [BMC+09], the consideration of this duality in the study of social acceptance in HCI[2] was formalized by Montero et al. [MAM+10] who introduce an overall measure of social acceptance composed of two dimensions:

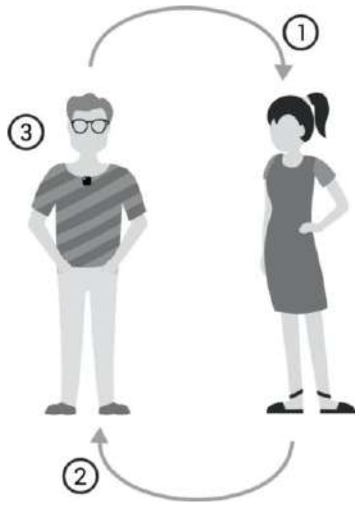
- The *user's social acceptance*, defined as the internal effect of the interaction that will leave the user with a subjective impression.
- The *spectator's social acceptance*, defined as the external effect of the user's interactions. Spectators perceive the user's interactions with the device that contribute to the spectator's impression of the user.

Taking into account that social acceptance is not a one-time decision between acceptable and unacceptable, but rather a *"user's continuous decision process that is influenced by the experiences gathered while performing"* [Wil12], we can describe the *social acceptability of a human-machine interaction* as a process (c.f., Figure 2.2) consisting of (1) the user's performance and the impression it creates in terms of both the *internal effect* (c.f., *user's social acceptance*) and the *external effect* (c.f., *spectator's social acceptance*). As the user would want the interaction to be consistent with their self-image and to receive positive feedback, they will (2) evaluate their internal impression along with a higher level interpretation of the spectators' feedback. Subsequently, they will (3) adjust their interaction accordingly or cease interacting. In consequence, we can specify a working definition of a human-machine interfaces *social acceptability* as follows.

> **Working Definition:** A human-machine interface can be considered *socially acceptable*, if its presence or the user's interactions with it are consistent with the user's self-image and external image, or alter them in a *positive* way. Human-machine interfaces that cause a *negative* change to self- and external image show a lack of *social acceptability.*

[2] Brewster et al. [BMC+09] use the term *social acceptability* whereas Montero et al. [MAM+10] use *social acceptance* contributing to the impression that researchers in HCI tend to use these two terms interchangeably, as also noted in [KOM+19].

It lies in the nature of this (iterative) process that it changes over time: while the user gains more experience with the interaction, they might grow accustomed to previously unfamiliar interactions or also collect more, and potentially more diverse and controversial feedback from spectators. In addition, a user's aspirations, i.e., the public image of themselves they would like to convey, is also bound to change. Last but not least, social and cultural expectations may develop and change over time which shapes the (positive or negative) feedback conveyed through different audiences.



1. **Performance & Impression** The user's interaction with the system (performance) shapes their and their spectator's subjective impression.
2. **Evaluation & Feedback** The user evaluates the internal experience against their aspirations and collects feedback from present or imagined spectators (external effect).
3. **Adjustment** The performance is adjusted accordingly. It may alter, e.g., invert or reinforce, the impression created by the previous performance.

Figure 2.2: Social acceptability of a human-machine interaction as a process of impression management.

Discretion: Impression Management and Privacy Breaches

Extending his metaphor of public performances, Goffmann [Gof59] distinguishes between a "front stage" (or front), and a "back stage" (or back). The front is where the performance is given, i.e., where the user (or "actor") aims to embody certain favorable characteristics. In contrast, the back is kept closed from the "audience". Here, facts or behavior that the "actor" wishes to keep private make an appearance. In consequence, an actor's impression management can be impaired, when the barrier between front and back (the metaphorical stage curtain) is breached. This can be the case, if the presence of an interface, or interactions therewith, yield "too much" information about the user, or another actor, i.e., if a breach of privacy occurs. The original conceptualization of privacy as a state of psychological security that can be distorted or injured when information about a person's "private life, habits, acts and relations" becomes available to others [Gla79], further explains this close relatedness: privacy breaches constitute a threat to impression management.

A human-machine interface can pose a threat to both, the user's and the bystander's impression management and privacy. In the first place, interacting

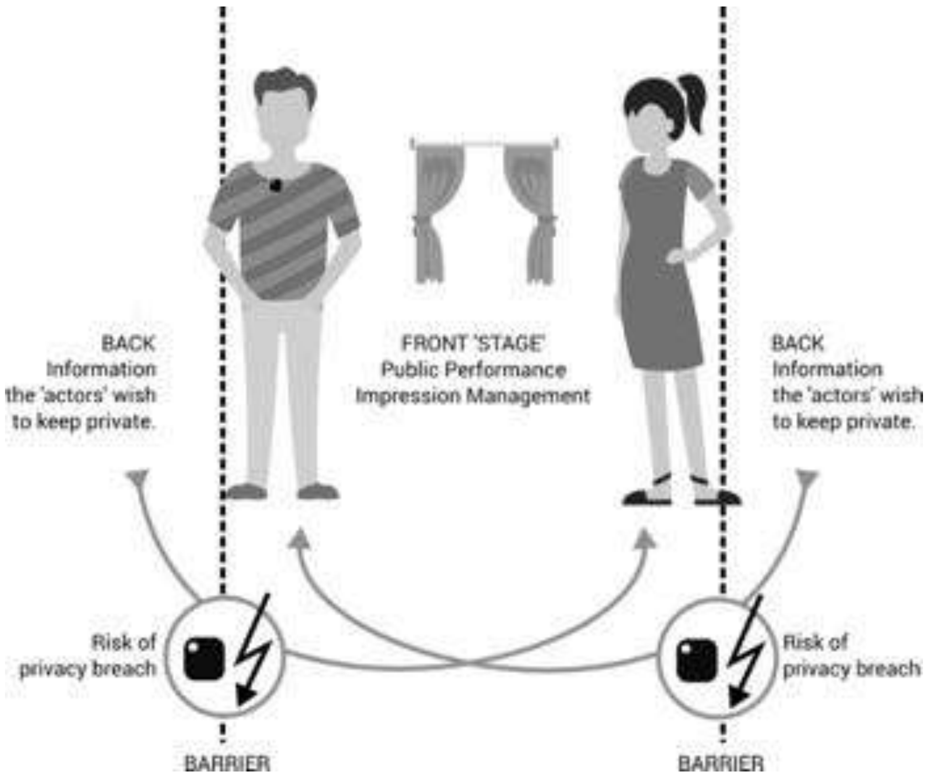


Figure 2.3: Using a dramaturgical metaphor, Goffman distinguishes between front "stage" and back "stage" [Gof59]. While front is where the public performance takes place, the back includes facts that the "actors", i.e., user (left) and bystander (right), wish to keep hidden. A wearable camera device poses a threat to the barrier between front and back.

with an interface might reveal information about the user that they desire to keep hidden (e.g., a health condition). In consequence, the barrier between front and back is not maintained; the interaction with the device might be perceived stigmatizing, or not socially acceptable. Secondly, some interface or device types can pose a threat to the privacy of other actors (e.g., bystanders): they might make information kept in the back accessible to persons other than the actor (see Figure 2.3). In the case of wearable cameras, this effect intensifies further, as the threat to bystander privacy originating from the camera reflects back poorly on the user's own impression management. Even if the camera wearer does not follow malicious intents, the device is harmful to other actors' impression management: in conversations, human memory keeps only an essence, while a large amount of small details passes away unnoticed, or is forgotten after a short period of time. Computers, in contrast, have "perfect memory". In consequence, to use of body-worn camera devices in social context (e.g., within a "team" of conversational partners), poses a threat to what Goffman describes as "discretion": a performer with discretion *"is someone with 'presence of mind' who can cover up on the spur* *of the moment for inappropriate behavior on the part of his teammates, while all the time maintaining the impression that he is merely playing his part"* [Gof59]. As a result, the a camera wearer might no longer be considered a team member that is trusted to have discretion.

In short, if the user wears a recording device in social context, consequential privacy breaches pose a threat to their bystanders' impression management, which in return negatively affects the user's own impression management, as they would want to be considered trustworthy.

Social Acceptability and TAM

Social acceptance is not always clearly distinguished from user or technology acceptance [MAM+10]. Evaluations of user acceptance (or technology acceptance) typically refer to Davis' well-known and broadly used Technology Acceptance Model (TAM) [Dav86] which defines the adoption of new technologies by individuals based on two main factors: perceived usefulness (PU) and perceived ease-of-use (PEOU). We find these in the context of Nielsen's idea of *system acceptability* (c.f., Figure 2.1) referred to as *usefulness* (resp. *utility*) and *usability*, and classified under *practical acceptability*. There are derivative models (e.g., UTAUT) that add subjective norms and social influence (SI) [MG99; VM00] to the original TAM. Further extensions, e.g., by Kim et al. [Kim15] who investigate the "subcultural appeal" of smart watches being a fashion statement, even brush aspects of impression management by taking a desirability perspective on interfaces that might be considered "cool" or "trendy". These derivatives of TAM share the assumption that individuals tend to consult their social network in order to reduce anxiety towards adopting an innovation [KSC99]. All those models have in common that they describe a causal relationship between TAM's (or UTAUT's) factors (PU, PEOU, SI) and the user's decision making process.

There are clear parallels between *technology acceptance* as described by TAM/-UTAUT and a human-machine interface's *social acceptance* as discussed above: both describe a decision making process with the user's intention to use as central element. As noted by Hornbæk et al. [HH17], TAM and its derivatives do not account for negative emotions and psychological needs. On the other hand, social acceptability is typically defined through negation, specifically the absence of social disapproval (c.f., APA Dictionary of Psychology [Van07]), and the need for social approval respectively. The concept of *social acceptability* based on the human-machine interaction's effect on *impression management* includes both, positive feedback (social approval) and negative feedback (social disapproval). Using a scale metaphor (see Figure 2.4) we can describe TAM/UTAUT and social acceptability/impression management as complements. The decision process to use (or keep using) is influenced through TAM's factors PEOU and PU on one side (encouraging, left), and *negative* social judgment, i.e., a lack of social acceptability, on the other side (discouraging, right). In addition, *positive* social

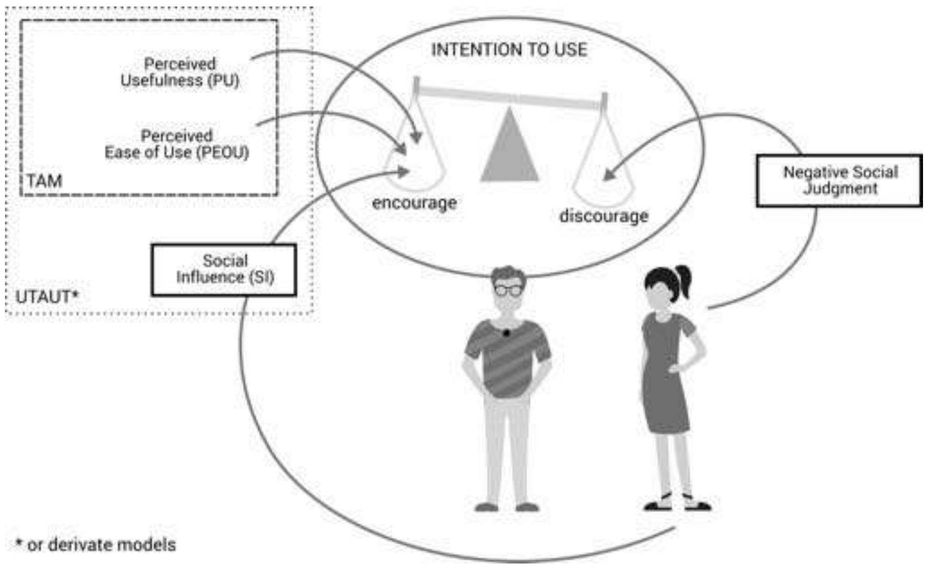


Figure 2.4: The relationship between TAM/UTAUT factors and social acceptability can be illustrated using a scale metaphor. Factors encouraging interaction (PU, PEOU, SI) on the left, factors discouraging interaction (negative social judgment) on the right. Both positive feedback (social influence, SI), and negative feedback (or social judgment) can be present in the process of impression management.

influence (SI) can be ascribed to the positve, encouraging side. It is present in both, UTAUT [MG99; VM00] and impression management [Gof59]: positive feedback encourages the user to start or keep interacting and indicates social acceptance of interface usage. Moreover, we note that discouraging factors (right) are not necessarily confined to *negative social judgment*, but may include further negative impact from interface usage, as e.g., comprised by Suh et al.'s user burden scale [SSH$^+$16].

In summary, the joint consideration of TAM/UTAUT and impression management illustrates that the decision to (not) interact with a device is typically a result of weighing benefits: perceived usefulness, perceived ease of use, and positive social influence act encouragingly, negative social judgment (i.e., a lack of social acceptance) acts discouragingly. We note however, that actual or perceived utility (as in TAM) can have an influence on (negative) social judgment, which will be more attenuated if it is understood that "the user needs the device" [PAF$^+$16]. In consequence, while we do not explicitly include work on TAM in the subsequent literature analysis (Section 2.2), elements of TAM/UTAUT are present in some measuring instruments, or constructs used by the selected papers. TAM factors, specifically perceived utility, are also present to some extent in the remainder of this thesis, e.g., in the ranking of factors influencing adoption presented in Section 3.2 (ranking of influencing factors) and 6.1 (design of user studies).

2.2 Review of Existing Research Practices

There is a lack of agreed-upon methods and measures to evaluate and quantify the social acceptability of an interactive system. Simultaneously, *social acceptability* is often encountered as a by-product during user studies, and often only become apparent through its absence e.g., when interfaces are not interacted with during in-the-wild experiments or not adopted on their market entrance. Design strategies for increasing an interface's social acceptability have been employed and in parts empirically verified for individual interface types, interaction paradigms, or application areas, but so far not holistically appraised and evaluated.

With this section, we contribute a holistic view of the current perspective HCI research takes on social acceptability. Specifically, we conduct a structured literature review (N=69) to answer the research question

> **RQ1:** Which methods, measures and design strategies are employed to evaluate, quantify, and influence the social acceptability of human-machine interfaces?

We make the following three contributions: First, we analyze how the social acceptability of interactive systems has been evaluated in HCI. We outline and discuss methods and measures in terms of their distribution, replicability, internal, external and ecological validity. Second, we provide an overview of design patterns that have been employed to increase the social acceptability of interactive systems. In particular, we discuss to what extend they have been empirically confirmed. Third, we identify methodical gaps concerning social acceptability in HCI, and discuss challenges and opportunities to guide future research in this area.

Selection of Papers

Informed through the approach taken by prior literature reviews in HCI [HH17; SEU$^+$18; PMH19], we employed a process of browsing, screening, backward-chaining, and final appraisal. We used the ACM Digital Library (ACM-DL) as initial outlet where we conducted a keyword search using variants of the word combinations *social acceptability* and *social acceptance*, including different grammar forms as in Figure 2.5. We conducted our search in Q1/2019 and limited it to publications between 2000 and 2018, which yielded 164 entries in the ACM-DL.

All query results were screened according to 4 inclusion respectively exclusion criteria, namely: (1) the work is original, peer-reviewed research; i.e., we excluded workshop proposals, newsletter, commentaries and summaries, as well as student theses. The work (2a) contains a formal or informal evaluation or measurement of social acceptability, or (2b) names social acceptability as design goal for a presented prototype or interface, or (2c) names design recommendations for socially acceptable interfaces. (3) the work covers the social acceptability (from user and spectator perspective) of a user's interaction with a system, interface

```
"query": {("social acceptability"; "social unacceptability";
"social acceptance"; "social unacceptance"; "social
nonacceptance"; "socially acceptable"; "socially unacceptable")}
"filter": { Publication Date: (01/01/2000 TO 12/31/2018), ACM
Content: DL }
```

Figure 2.5: Search query used for key phrase search in the ACM Full Text Collection (matches "`any field`"); Publication years 2000-2018.

or technology; i.e., we excluded work on virtual agents or (humanoid) robots. We explicitly did not target autonomous systems that aim to achieve sociable or socially acceptable behavior by adopting or mimicking (human) behavior. These include (humanoid) robots [TTZ17] or autonomous cars [CTS+17]. For a survey in the context of social robotics, we refer to Savela et al. [STO18].

Screening was conducted by two researchers separately based on the aforementioned criteria, paper titles and abstracts and by skimming the paper's full texts. Their 88% accordance indicates a substantial inter-rater agreement [LK77] with $\kappa = .72$ (95% $CI, .60\ to\ .84$). Discrepancies were discussed on a per-paper basis, resulting in an initial set of 47 papers.

To account for publication venues not included in the ACM-DL, we employed backward-chaining, i.e., we additionally evaluated all papers referenced by the works selected in the previous step against the inclusion and exclusion criteria (snowballing principle). This yielded 23 additional papers.

For final appraisal we considered again all resulting full texts. At this stage, we excluded one paper ([NJ08]) that contained social acceptability in the abstract, but its remainder focused on the TAM factors perceived ease-of-use, perceived usefulness without addressing (positive or negative) social influence. The final set (N=69) included conference papers of varying length (n=55) and extended abstracts (n=10) as well as journal articles (n=4). A majority of papers was published at CHI (n=20), followed by MobileHCI (n=10), UIST and TEI (n=4 each), and ICMI, and ASSETS (n=3 each). The 69 reviewed papers are marked with **bold** labels in the reference list.

Analysis and Synthesis

We identified 46 (67%) papers that presented a formal or informal evaluation or measurement of social acceptability (2a). 52 papers suggested or employed design strategies to increase the social acceptability of an interaction or interface (2b). 29 papers contained both, user studies and design strategies (see Figure 2.6 for an overview). Only 7 papers named concrete design recommendations (2c).

Figure 2.6: We analyzed the overall 69 papers for methods and measures (46 papers) and for design strategies (52 papers).

We employed a strategy of clustering, and additional closed coding for methods and measures, respectively open coding for design strategies. We furthermore grouped all papers according to their research contribution based on [WK16], and study type as defined and discussed by Kjeldskov et al. [KP12; KS14]. For papers that contained multiple subsequent studies or experiments, we only considered those that evaluated social acceptability. Mixed method approaches or combinations are counted for each study type.

In the following, we outline the results of this analysis, specifically, in terms if methods and measures (46 papers), and design strategies (52 papers). We name and discuss benefits and disadvantages of each method, particularly with regard to ecological, internal, and external validity, as well as reliability, and applicability. We highlight that each of the analyzed methods and study designs, despite having both advantages and disadvantages, provides a valuable contribution that helps to better understand social acceptability issues with human-machine interfaces. Thus, instead of singling out flaws of individual studies, or designs, we aim for a more holistic view of how social acceptability is addressed in current HCI research. By mapping methods and design strategies this overview paper provides a basis for identifying best practices.

In particular, we point out research gaps, both in terms of methodical contributions and study methods, and under-evaluated aspects of socially (un)acceptable designs, that will allow for a more nuanced view of study methods, and create a valuable basis for future research.

Limitations

The use of the ACM-DL as initial outlet may induce certain limitations. Querying only titles and abstracts yielded only 20 publications (all included in the analysis). Thus, we expanded the scope of the query to include further fields. As also noted by Pohl et al. [PMH19] a query in the ACM-DL yields different results when applied to "`full-text`" respectively "`any field`". While we used the latter, similar to Pohl et al. [PMH19], we also did find no apparent evidence for a systematic bias introduced through this procedure. However, persistence of meta-data is indeed a common issue with digital libraries [MG01]. In consequence, a search query can yield slightly divergent results depending on the time of search; for instance due to adaptation of retrieval and ranking algorithms in the digital libraries back end. For this reason, we employed backward-chaining to rule out systematic bias introduced through the ACM-DL's organization of meta-data.

2.2.1 Methods and Measures

In this section, we only consider the 46 (68%) papers that contained a formal or informal evaluation of social acceptability, all of which empirical, i.e., user studies. Of this subset of 46, 35 papers evaluated the user's perspective, 17 the spectator's perspective; 14 included both, the user's and the spectator's perspective. Only 8 papers evaluated general views, neither explicitly user or observer. In the following, we detail on study settings, procedures, and employed scales and measures.

Staging Experiments: Online, Lab & Field

Social context is typically mediated through location. Thus, we first report on the study settings and locations where the analyzed user studies were conducted.

Figure 2.7: We analyzed current practices in researching social acceptability in HCI.Common study settings include online surveys (right), e.g., collecting ratings of video prototypes [RB10a], and field experiments with the researcher present, e.g., in public indoor locations [AHI14] (mid left) or outdoors [LV14] (mid right). Only few studies simulate social context in laboratory experiments [TBS18] (right).

Surveys

Social acceptability largely depends on subjective perception and individual opinions. Thus, it is not surprising that a popular way to evaluate social acceptability are surveys (n=16), of which a large number were conducted online (n=11 online, n=5 in the lab). We found a large variation in the number of survey participants (M=254, SD=382): from 20 in [GLV+17] to 1200 in [PAF+16]. Only a small number of the analyzed surveys were purely textual questionnaires [MAF+17; OSP+17; NBA17; Cam07; GLV+17]. The majority of both surveys conducted online, and surveys administered on-site, use videos (n=7), animations (n=2) or still imagery (n=3) to present the (remote) participant with a fictive scenario in which the interface would be used. Except in [FBL14] where remote participants were asked to try out gestural interaction as shown in the videos contained in the online questionnaire, participants in the analyzed studies were not explicitly encouraged to interact. In consequence, imagining themselves in the user role, e.g., performing unfamiliar interactions, often required guesswork by the participants. Although less severe, this imaginary component, which requires the participants to put themselves into a situation potentially never experienced before, might also affect questionnaires completed from a bystander perspective. While this lack of firsthand usage experiences has been criticized, e.g., by Ahlström et al. [AHI14], there are indicators that (crowdsourced) surveys can still be a viable alternative to laboratory experiments when evaluating social acceptability [ANS+18b]. In addition, surveys administered online may also allow for larger, and more regionally or culturally diverse samples [LHF17], and thus can support generalizability [FH03].

Lab Experiments

A large portion (n=16) of the user studies included in the analyzed paper set was conducted as *lab experiments* (defined according to [KP12]), i.e., in controlled laboratory environments involving one or more experimental conditions. All 16 lab studies asked the participant to either interact with a prototype or device, or to act out some kind of interaction, e.g., a gesture or voice command: *"Participants watched a video of an actor performing panning and zooming gestures in front of a wall and then performed themselves the same gestures 3 times"* [SEI14]. Naturally, the increased level of control comes at the cost of a decreased ecological validity [KS14]. In a controlled, less vivid laboratory setting, devices and interaction styles might appear more salient than when tested in the field.

Field Experiments

In order to increase ecological validity, another large portion of studies (n=13) was conducted in natural settings, under controlled but realistic conditions with the researcher(s) present. Following the classification of research methods by [KP12] these studies would be classified as *field experiments*. A common practice for *field experiments* on social acceptability seems to be to choose highly frequented public locations as study setting, such as shopping malls [AHI14; AF18], urban parks [AF18; LV14], cafés or restaurants [HSP+08; LLS+18; THW+15], bus stops or public transport [MCP+04] and pavements at busy streets [RB10b; Wil11;

LV14], but also locations on campus, such as university atrium [ANS+18b], or university cafeteria [HSP+08; PKR+17].Lucero et al. [LV14] designed a walking route that included a busy main road, urban parky, crossing a bridge over a river, walking past a pub terrace, and near a kids' playground. They argue that this allowed the participants, with the researcher following a couple of meters behind, to experience a range of casual audiences (c.f., Figure 2.7, mid right).

The choice of easily accessible public locations (e.g., cafés) has a number of advantages, including convenience, naturalness, and a large casual audience. However, experimental control is limited. In contrast to lab studies, busyness of places might not be constant, having potential effects on replicability and comparability. This is notable, as only very few papers contain information about presence and number of casual bystanders and passers-by (e.g., Lucero et al. [LV14]).

Field Surveys

Only three of the analyzed papers presented *field surveys*, which we define following Kjeldskov and Paay [KP12] as natural setting research where data collection methods such as diaries, log files, interviews etc. are used, instead of the researcher being present in the field. For example, Häkkilä et al [HVC+15] employed the Experience Sampling Method (c.f., Larson and Csikszentmihalyi [LC14]) to evaluate a smart glasses prototype in terms of privacy and social acceptability with regard to different contexts and interaction modalities. During a 5-day diary study, participants were prompted per text message, and asked to describe their current context (e.g., *"Approximately how many people were around you? What was their reaction?"*) along with imagined uses of the smart glasses device. On the first two days of the study, participants carried a smart glasses prototype with them that they put on as soon as possible when prompted. Williamson et al. [WCB11] measured participant's interaction rates and subjective experience with regard to sensory determined context and activity (walking, using public transport) while interacting with a multimodal RSS reader during their daily commute. Another work by the same authors [WBV13], participants were encouraged to play a gesture-based mobile game in daily live while collecting usage logs, and user-reported data on location and user experience. While these methods are inevitably costly and time-consuming, they also provide a high ecological validity, and are able to uncover unanticipated motives, biases, and social acceptability issues [KS14].

Creating User Involvement: Study Procedures

Social acceptability is to a large extent experiential, and an aspect of social life that participants will typically be familiar with. Creating different types of user involvement as part of the study procedure can account for this.

Experimental Control and Stimuli

We found the analyzed studies to employ different stimuli and forms of experimental control. 59% of user studies included hands-on experiences (n=27) either with a prototype or off-the shelf device, or by trying out an interaction method. In the latter case, user interfaces were imagined, i.e., participants were instructed to act out the interaction (e.g., gesture or voice command) without a device or interface present. A small number of studies also provided the opportunity to observe other participants (n=5) while performing. Only one paper (Monk et al. [MCP+04]) involved only the researcher interacting with an interface. We further found that videos (n=14) have been re-occuringly used as stimuli in both, online surveys and lab experiments (here partially for instructory purpose). However, the extend to which the videos are shot in a way that depicts realistic interaction scenarios varied: while some studies purposefully aimed for *neutral* videos, e.g., an actor in front of a white wall [RB09; SEI14], others were shot to depict scenarios as realistically as possible, e.g., at a bus stop [PAF+16] or at varying locations, including a café, library, or street [RHK+07].

Co-creation and Discussion

Only a small number of papers actively involved their participants in the design process. Five papers presented guessability-style elicitation studies (n=5), and three papers reported having conducted focus groups (n=3). Except for where general HCI research practices can be applied (c.f., Wobbrock et al. [WAR+05] for elicitation studies) there is no established procedure on how to co-create ideas for socially acceptable interactions or interfaces. Lee et al. [LLS+18] suggest: *"To focus the study on social acceptability, we further adapted typical elicitation methods. To improve the ecological validity of the proposed actions, the study was conducted in a busy public place – a coffee shop"*. This illustrates that there is no existing guidance or practice on how to integrate the users' (or bystanders') views on social acceptability more directly in the design process (yet).

Quantifying Social Acceptability: Scales, Questions, & Measures

As social acceptability is largely determined by the user's personal experience and how they subjectively perceive feedback from a present or imagined audience, it is not surprising that the majority of studies is based on subjective-quantitative (n=31), or subjective-qualitative (n=26) measures, where the latter is typically obtained from qualitative interviews, or open-ended survey questions. Only five of the analyzed papers (all of which focused on gestures) explored objective measures, such as interaction rates [WBV13; WCB11], or interaction parameters such as duration, amplitude, or energy [WMS14; THW+15; RB10b]. We also found a small number of study designs, where nominal data on social acceptability was collected, e.g., when participants had the choice to reject certain interaction areas or styles for social or personal reasons [KWL+11].

While a majority of studies used self-defined questionnaires (n=30), or made use of the audience-location axes introduced by Rico et al. [RB10b] (n=15), we found only two papers that employed cross-validated scales, namely the WEAR Scale [KG16] and the I-PANAS-SF [VBS15], a (international) 10-item scale assessing positive and negative affects [Tho07]. A questionnaire developed by Profita et al. [PAF+16] (c.f., Figure 2.10) was taken up by one other work [SRR+18]. In the following, we go further into detail on how subjectively perceived *social acceptability* is quantified using questionnaires. In particular, we discuss the use of single-/multi-item scales, paraphrases for *socially acceptable*, and the use of *audience and location* as a proxy for social acceptability.

> How would you feel using this menu on the scale of 6?
> *(1-Embarrassed to 6-Comfortable)*
>
> How would you feel watching someone other using this menu on the scale of 6?
> *(1-Foolish to 6-Sensible)*

Figure 2.8: Considering both the user's and the spectator's perspective; Two 6-pt Likert scales by [VBS15].

Single-/Multi-Item Scales and Periphrases

Direct inquiry, using a single-item scale is the most simplest way to approximate how socially acceptable a device or interaction method is perceived: e.g, Kim et al. [KSP+06] ask *"Social acceptance: is it acceptable to wear it in daily life?"*. In [KAC+18] the authors employ a combination of two items, namely comfort (*"How comfortable would you feel performing this gesture in an everyday public setting, such as a busy sidewalk?"*) and social acceptability (*"How acceptable would it be to perform the presented gesture in public?"*) to assess both user's and more general/bystanders' perspectives (5-pt. Kunin scale). Similarly, Pearson et al. [PRJ15] employ a 5-pt. Likert scale from 1 (*"completely unacceptable"*) to 5 (*"completely acceptable"*) to determine how participants rated the social acceptability of peeking at one's own/another persons watch during face-to-face conversations. These two examples are representative for quantifying social acceptability on 1 to 5 or 1 to 7 scales using Likert [Lik32] or Kunin scales [Kun55]. But we also found studies to use other types of response options, e.g., single- or multiple-choice answers. For example, Ronkainen et al [RHK+07] combined aspects of desirability and willingness to use (*"Would you use this feature in your phone?"*) in a single-choice question providing different reasons for a yes/no decision (c.f., Figure 2.9a). Similarly, Ahlström et al. [AHI14] employ multiple-choice options featuring a range of reasons and impressions (e.g., *"I thought it looked fancy"*). While questions asked this way yield only nominal data, and thus have limited statistical power, they can help to better understand how users or observers feel about a given situation. Nevertheless, the fixed number of response options, and the way how they are phrased, might also introduce bias, and skew the given answers towards the given responses [GFC+09].

> Would you use this feature in your own phone?
> *Yes, it's fun / Yes, it's useful / Yes (other reason) / No, it looks silly / No, it's not useful / No (other reason)*

(a) Single-choice questionnaire used by Ronkainen et al. [RHK+07] in an online survey. It combines aspects of impression management and perceived usefulness.

> What were you thinking watching me gesturing around my phone, the way I just did? Select **one or more** items from the list below.
>
> ☐ I was wondering what you were doing
> ☐ I did not think much about it
> ☐ I thought it was annoying /disturbing
> ☐ I thought it looked fancy/interesting
> ☐ I thought/my impression was:
> ☐ I thought "what a weird behavior"
> ☐ I thought it looked stupid/strange
> ☐ I thought the movements were inappropriate

(b) Multi-choice question asked to interested bystanders of a staged interaction [AHI14].

Figure 2.9: Social acceptability is often paraphrased using a range of adjectives; Single-choice (top) and multi-choice variants (bottom).

As also illustrated by these examples, *socially acceptable* human-machine interactions are often described or paraphrased using a range of adjectives that relate to *impression management*, occasionally combined with aspects of perceived usefulness or perceived utility. This approach can be beneficial, as it might be unclear, what *socially acceptable* means to a user, and whether study participants understand *social acceptance* the same way as the researchers. We provide an overview of adjectives employed to paraphrase *socially acceptable* in Table 2.1. Many of those adjectives are loosely tied to *impression management*, or how a user's interactions might be perceived by others. However, conceptualization attempts (as discussed in [KOM+19]) are only sparsely present in the analyzed set of papers. There is (so far) limited knowledge on how individual adjectives or items might cohere, or relate to superordinate constructs. We find a strong focus on adjectives with a negative connotation (e.g., weird, annoying), which reflects *social acceptance* being typically defined through negation, or an absence of negative judgment (c.f., Section 2.1). We also found a similar choice of adjectives to be used to replace *socially acceptable* – *socially unacceptable* in rating scales (e.g., Likert scales). Examples include e.g., *embarrassed – comfortable, foolish – sensible* [VBS15]; c.f., Figure 2.8. Similarly, semantic differentials, i.e., sets of multiple, bipolar pairs of adjectives (c.f., [MR74; BL94]) have be used to measure the emotional response of participants, more specifically their attitude towards an interaction with a device in a certain situation or scenario [KKM15; KEC+17].

Summing up, in terms of single- or multi-item scales, there is no agreed upon way to ask for *social acceptability*. Although there are questionnaires that have been re-used [PAF+16; SRR+18], as well as sets of cross-validated items that have been proposed [KG16; VBS15], evaluations largely depend on self-defined, custom questionnaires. These practice induces a couple of potential issues, including low comparability and potential bias or skew. In addition, questions are often phrased to exactly match the to-be-evaluated prototype or interaction style. In consequence, they are often not well transferable and do not well generalize. The practice to use adjectives to paraphrase *social acceptability* can be beneficial in terms of illustration (e.g., Figure 2.9), but might induce the danger of a reduced reliability due to untested selectivity/separation effects between adjectives if used as single choice questions. It is furthermore unclear to what extend the selection of used adjectives overlaps with other constructs that might or might not correlate with social acceptability, e.g., hedonic quality [HPB+00; Has04]. These aspects illustrate the difficulty of creating a set of questions/items that provides a reliable and transferable measure of *social acceptability*. The use of audience-and-location axes to proxy social acceptability, which we will discuss in the next section, seems to be a popular way to circumvent these.

Audience-and-Location Axes

Although the use of *location* to describe *social occasions* as a proxy measure for the *social acceptability* of a human-machine interaction had already been employed earlier [Cam07], Rico's and Brewster's "audience-and-location" axes, as first presented in [RB09; RB10a], were the most widely used quantitative measure for *social acceptability* in the pool of analyzed papers (n=15). Their selection of audiences (alone, partner, friends, family, strangers, and colleagues), and locations (at home, while driving, as a passenger on a bus or train, on the pavement or sidewalk, at a pub or restaurant, and at the workplace) has been taken up, employed, modified and extended by numerous researchers. Depending on the evaluated interaction methods and evaluation context, some of them excluded "while driving" [BMR+12; HJO+16] or added locations, e.g., "museum" and "shop" [AHI14]. Other authors grouped audience and location into plausible "social situations", e.g., Home, family; Work, colleagues [FBL14; SEI14]. The questionnaire has been adapted for different types of interactions including wearable devices and sensing [BMR+12; GLV+17], on-body or textile input [OF14; PCG+13], and employed in lab (n=6), online (n=5) and field (n=5).

At first, the audience-and-location axes were phrased as multiple choice questions: *In which locations would you use this gesture?*, and *Who would you perform this gesture in front of?*, respectively. This yielded binary ratings for each location/audience; results were then aggregated as scores (or "acceptance rates"), *Statements about the interaction:*

1. It looked awkward when this person was using the wearable computing device. **(Awkward)**
2. It looked normal when this person was using the wearable computing device. **(Normal)**
3. It was appropriate for this person to use the wearable computing device in this setting. **(Appropriate)**
4. It was rude for this person to use the wearable computing device. **(Rude)**
5. I felt uncomfortable watching this person use the wearable computing device **(Uncomfortable)**
6. I would be distracted by this person if I were at the bus stop with them. **(Distracting)**

Statements about the user:

7. This person seemed independent. **(Independent)**
8. This person needed help. **(NeedHelp)**
9. This person needed the wearable computing device. **(NeedDevice)**
10. This person looked cool. **(Cool)**
11. This person looked nerdy. **(Nerdy)**

Statements about the device:

12. The wearable computing device seemed useful. **(Useful)**
13. The wearable computing device seemed unnecessary. **(Unnecessary)**

Figure 2.10: Multi-item questionnaire, designed by Profita et al. [PAF+16]; also used as a slightly modified version by Schwind et al. [SRR+18].

	cool	fancy	interesting	fashionable	stylish	useful	nerdy	natural	normal	noticeable	weird	embarrassing	annoying	disturbing	stupid	strange	inappropriate	awkward	impolite	silly	intrusive	rude	creepy	disfiguring
[AHI14]		*	*								*		*	*	*	*	*							
[Cam07]																	(*)					(*)		
[HVC+15]					*																			
[KG16]	*			*	*	*		*	*		(*)	*	*				*	*				*	*	*
[MCP+04]										*			*								*			
[MAM+10]												*												
[PAF+16]	*					*	*		*					*			(*)	*				*		
[PCG+13]	*							*	*		*	*	*					*	*	*				
[RHK+07]						*														*				
[SRR+18]						*			*								(*)	*				*		

Table 2.1: Adjectives used to describe or paraphrase *social acceptability* in questionnaires. Asterisks in brackets (*) indicate the use of a negation, e.g., ‘not weird’. Negative adjectives (right) are more frequently used than positive (left) or neutral (middle) adjectives, which reflects how social acceptability is often defined through the absence of negative feedback.

typically calculated as a percentage of positive responses [FBL14; RB10a; HJO+16; LLS+18]. To increase explanatory power, the questionnaire was later adapted by other researchers using various Likert scales: for example 5-pt. [ANS+18b; ANS+18a], as listed in Figure 2.11, or 10-pt. scales [BMR+12].

The audience-and-location axes have the advantage of a clear discriminatory power, and are easy to understand (for both researchers and participants) and easy to use. They do provide a very useful metric for an interaction's overall social acceptability, based on the fundamental question "would the user be willing to interact with the system?". On the other hand, they only provide a somewhat "absolute" measure of social acceptability. Albeit the choice of independent variables (e.g., by evaluating different variants of an interaction) can provide some indication, the measure itself does not provide insights about what factors contribute to an interaction being more or less socially accepted. In particular, audience and location do not provide insights about the experience, or emotional response, to the evaluated interactions.

In principle, "acceptability scores" could be compared across multiple studies. However, this is not easily possible with the present set of studies: different works compute scores differently, e.g., as percentage of positive responses per location/audience [AHI14; RB10a], or as the percentage of selected audiences/locations per experiment condition [LLS+18]. Moreover, only few papers reported all obtained scores [FBL14; HJO+16; OF14]. Instead, most of the analyzed papers only reported selected scores (e.g., for one specific gesture), or used bar bar-chart representations to illustrate relative scores (e.g., of different experiment conditions) without providing actual numbers. In consequence, comparability of scores is (so far) limited. Most notably, there is – to the best of our knowledge – no work on the measuring instrument itself. Albeit results seem to be consistent across studies (as noted by Freemann et al. [FBL14]), the audience-and-location axes are not (yet) validated in a strict sense. Specifically, it is so-far unclear what constitutes an "acceptable" social acceptability score: while a low score indicates that an interaction technique or interface will most likely have social acceptability issues in the field, it is unclear if a high score, although promising, can predict or guarantee socially acceptable interaction in the field; An uncertainty which is not unique to the audience-and-location axes, but had , for instance been noted on the system usability scale (SUS) [BKM08].

2.2.2 Design Strategies

Improving social acceptability can motivate designing an interface or interaction technique in a specific way. Similarly, certain design features can turn out to hinder or promote social acceptability. While not all of the analyzed N=69 papers elaborate on how social acceptability can be influenced (either positively or negatively) through the design of interface or interactions, we found *design strategies* to increase social acceptability to be a re-occurring theme (n=52). Twenty-nine papers discuss or present design strategies as a result of their empirical research. Seven of them provide concrete design recommendations or best practices [AHI14; ANS+18a; FBL14; KKM15; RB10a; SW11; WCB11], all of which empirically backed. In addition, we found 23 papers to employ design strategies to increase

On a scale of 1 to 5 (with 1 being **very socially uncomfortable**, and 5 being **very socially comfortable**), how do you feel performing **Voice Commands** input in the following locations, please rate the following locations you prefer?

	red1 Very socially Uncomfortable	2	3	4	5 Very socially Comfortable
On the sidewalk	○	○	○	○	○
At home	○	○	○	○	○
Public transportation	○	○	○	○	○
Workplace	○	○	○	○	○
Shopping mall	○	○	○	○	○

Figure 2.11: Quantifying *social acceptability*: Alallah et al. [ANS+18b; ANS+18a] use a combination of audience (not listed) and location (see example above) adapted from Rico and Brewster [RB10b] based on a 5-pt. Likert scale.

social acceptability in research prototypes (or modified consumer devices, c.f., Profita et al. [PSM+18]). Surprisingly, only 9 of them evaluate the effect of those strategies. In the following, we go into detail on which design strategies were suggested or employed, the contexts in which they were tested with users, and then combine and discuss the results comprised by all 52 papers.

Subtlety, Unobtrusiveness and Avoiding Negative Attention

The most popular strategy to create socially acceptable human-machine interactions is *subtlety* (n=32). In fact, as Pohl et al. [PMH19] note *"[t]here is a common underlying assumption that systems that are hard to detect by others increase social acceptability"*. While *subtle* can (in principle) be used to describe secretive or deceptive interactions [AGW+15; PMH19], the analyzed set of papers displayed a general tendency towards unobtrusive, but visible and revealed interactions as opposed to hidden interactions (c.f., Reeves et al. [RBO+05]). Choices of subtle (or unobtrusive) interactions were prevalently motivated by the designer's choice to *"de-emphasize"* [PFC15], or the users' desire to *"blend in"* [KHB17], *"not draw attention"* [OF14], or *"not advertise"* device usage [PFC15], as well as be non-disruptive. For example, Paay et al. [PKR+17] found participants to be conscious about not impairing others' physical space while (gesturally) interacting with large public displays, and to prefer techniques involving smaller movements. Similarly, in the context of around-device gestures, Ahlström et al. [AHI14] showed that small gestures, and gestures with a short duration were significantly more socially acceptable than more expansive, and more time-consuming gestures, as these avoid negative attention.

On the other hand, Rico et al. [RB10a] also note that *"the ability to disguise [some] gestures as everyday activities appears to make them more acceptable"*.

They exemplify foot tapping as a gesture that despite requiring relatively high energy to complete (i.e., having a large movement amplitude), is perceived as socially acceptable, due to its resemblance to tapping a rhythm while listening to music. Similarly, trouser pockets were appropriated to make interactions with interactive textiles less conspicuous and more natural [KWL+11]. Further elaborating on this approach, Lee et al. [LLS+18] identify miniaturizing, obfuscating, screening, camouflaging and re-purposing as design strategies for subtle, socially acceptable hand-to-face (gestural) input, and ask participants to come up with matching gestures. This procedure also illustrates, that in the context of social acceptability, subtlety is often understood as a prerequisite rather than a design strategy: *"Participants were [..] instructed to generate unobtrusive or subtle actions, suitable for use in the public setting of the study"*. We found 32 papers discussing or employing subtlety as a design strategy, but only 18 (56%) providing some (quantitative or qualitative) verification of the strategy's effect. In consequence, there is the risk that subtlety might be seen as universal remedy to social acceptability issues – while effective in some, also in cases where it is not.

Avoiding Suggestiveness & Misinterpretation

As impression management is largely concerned with how users expect to and want to be perceived by others, it becomes highly relevant how interaction techniques might be interpreted when observed. In consequence, the potential of a specific interaction to be misinterpreted can influence social acceptability. There is a multitude of scenarios, where an interaction with a device might be mistaken as (non-verbal) communication targeted at bystanders, e.g., insults (c.f., Serrano et al. [SEI14]) or could (potentially) be misinterpreted in a way that impairs the user's public image, e.g., scratching (c.f., Weigel et al. [WMS14]) as sign of poor body hygiene. Prior research in the area of gestural interaction confirmed, that commands that (inherently) emphasize that they are directed towards a device, are socially more acceptable than interactions that do not [RB10a; FBL14; MAM+10]. Rico et al. hypothesize: *"[U]sers are more willing to use a gesture if it provides visual cues that explain their behavior"* [RB10a]. Making the interaction context, e.g., the type of application or the user's intention, clear and observable can further avoid misinterpretation and increase social acceptability [KAC+18]. In the context of on-body and textile input, suggestiveness of certain body-areas can cause an interaction to be perceived as obscene or sexual. In the analyzed set of papers we found groundwork providing body maps [DPZ+14] as well as indications for e.g., gestures or body-areas that might be problematic [HSP+08; KWL+11; PCG+13], and reports of gender effects, e.g., different perceptions regarding the chest area [DPZ+14; PCG+13].

Accessory-like Shapes & Familiar Styles

Style of dress and impression management are tightly related. Similarly, wearable computing devices have traditionally aimed to emulate shape and styles of non-digital accessories. In consequence, the use of *accessory-like shapes* and *familiar styles* has been recognized and discussed as technique to increase social acceptability early on. Rekimoto et al. [Rek01] note: *"In other words, we believe 'unobtrusiveness' of input devices is essential for them to be used in everyday situations. One possible way to design such devices is to embed input sensors to conventional wearable items, such as wristwatches or clothing"*. In our analysis, we found these design strategies to be present in 12 papers of which half provided empirical evidence for its effectiveness (50%, n=6).

The use of familiar styles resembling non-digital accessories has been argued e.g., for (smart) glasses [HW17; MSO$^+$16], finger rings [OSO$^+$12] and smart watches [MLL$^+$11] or wrist bands [OSM$^+$13]. Dierk et al. [DSN$^+$18] explore hair as interactive material for inputs and outputs. They argue that *"[t]he surreptitious nature of the interface allowed a user to take an action without offending a friend or acquaintance"* and report that participants *"preferred the more subtle possibilities for technology embedded in something as ubiquitous as hair"*. This shows parallels to the appropriation of familiar, and thus perceived less obtrusive gestures [RB10a; KWL$^+$11; LLS$^+$18], as discussed in the previous section.

In the context of assistive devices, resemblance to non-digital accessories as well as non-assistive consumer devices has been reported to minimize stigmata [SW11]. Nanayakkara et al. motivate: *"The finger-worn device [..] follows this design paradigm: it looks and offers the same affordances and mode-of-use to both sighted and blind users in a self-sufficient way"* [NSY$^+$13]. In this context the resemblance to consumer devices can also be understood as a kind of *unobtrusiveness* or inconspicuousness, as it causes the device, and in consequence its user, to stand out less [PFC15].

Candidness, Transparency & Justification

The visibility of effects and manipulations, as formalized by Reeves et al. [RBO$^+$05], has been frequently linked to an interaction's social acceptability. While, as discussed in the previous sections, some prior work promotes inconspicuous, i.e., subtle or unobtrusive interactions, other researchers suggest to provide some explanation along with the interaction. Ens et al. [EGA$^+$15] promoted the social acceptance of their prototypes by making effects of the manipulations more observable, i.e., *candid.* While not as frequently employed as design strategy as *unobtrusiveness*, with only 4 papers[3] employing *candid* designs [EGA$^+$15; JP14; PF16; PSM$^+$18], we found candidness to be backed by multiple empirical studies (n=7).

[3] There is additional work employing candid designs, namely [KWH$^+$19], and [SKH$^+$19], that is not included in this analysis, but partially motivated by it and included in this thesis.

Referring to Reeves et al.'s classification of interfaces along the axes of hidden or revealed manipulations and effects (illustrated in Figure 2.12), interactions could be *secretive*, *magical*, *expressive* or *suspenseful* [RBO+05]. Ens et al. hypothesize that suspenseful interactions (revealed or amplified manipulations, hidden effects) tend to be socially awkward [EGA+15]. This suggestion is backed by earlier findings: For example, Montero et al. found magical (hidden manipulations, revealed or amplified effects) to be more socially acceptable than suspenseful gestures [MAM+10]. A similar effect had been observed even earlier by Monk et al. who compared the annoyance caused by overhearing a mobile phone call to overhearing a face-to-face conversation: social acceptance decreases when only half of the dialogue is audible [MCP+04]. Interestingly, the hypothesis that candidness increases social acceptability holds from both users' and bystanders's perspectives. Häkkilä et al. [HVC+15] report that in their studies, participants indicated a desire for justification: they were concerned about *"assumptions other people might be drawing about the expected use of the device. Several participants mentioned nearby people would think them doing something unethical or forbidden"*.

Most notably, the question *"what is done?"* respectively *"what is the purpose of the interaction?"* has been shown to have a significant effect on social acceptability as seen from a bystander's perspective [KKM15; PAF+16]. In addition, social acceptance can depend on utility, i.e., how helpful for the user the device is expected to be [AF18; PAF+16]. Profita et al. found that smart glasses used by a visually impaired person were perceived significantly more socially acceptable when the disability was disclosed [PAF+16]. In addition they found that social acceptability was affected positively when it was communicated *"how the device was used"*. More specifically, the interaction was rated with a higher social acceptability when the device was described as being used for an assistive purpose, and more negatively when being used for a personal purpose, or when no usage intention was specified. Similar effects have been described by Alharbi et al [ASV+18] and Ahmed et al. [AKP+18] in the context of wearable cameras. While these two studies do not focus on social acceptability and thus are not part of the analysis, they also illustrate that aspects of justification intensify (as suggested by Profita et al. [PAF+16]) where technologies are used that may affect bystanders more directly, e.g., those involving recording or sharing of information.

Finally, it has to be noted that a preference for *candid* or *transparent* design strategies does not necessarily imply that bystanders would be informed about all details of the interaction. It is rather about providing bystanders with a broad notion of what manipulations mean (as also suggested by Montero et al. [MAM+10]). Nevertheless, how this could be achieved by design is only sparsely covered in literature. Particularly the creation of a balance between privacy [EGA+15] or stigmata [SW11; PSM+18] and justification or bystander awareness [KWB18] seems to be a challenge for future research.

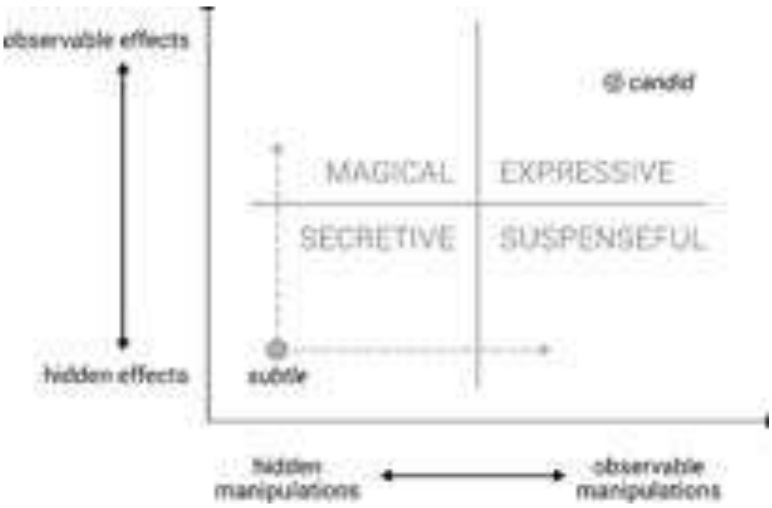


Figure 2.12: Interactions may hide or reveal manipulations and effects; Dimensions according to Reeves et al. [RBO+05]. Social interactions can be classified as magical, expressive, secretive and suspenseful. Interpretations of "subtle" vary [PMH19], whereas candid interactions are typically expressive [EGA+15].

2.2.3 Discussion

In this section, we reflect on our structured literature analysis, and discuss the impact of current practice and distribution of research and design approaches. We identify methodical gaps, and argue for a shift in direction to better address these gaps.

For more User Involvement, Ethnography & Co-creation

Social acceptability arises everyday, with digital and non-digital objects and with established and novel human-computer interfaces alike. Thus, we might expect users to be experts in impression management and social acceptability. However, we found that only 8 of the analyzed papers (12%) actively involved participants in the design process (c.f., the section on Co-creation and Discussion, and Figure 2.6). Only one paper looked into existing practices (glancing at one others watch, Pearson et al. [PRJ15]), albeit in a laboratory environment. None employed ethnographic methods, e.g., observational approaches in naturalistic settings. Instead, in the majority of studies, participants were asked to rate a pre-defined set of options (e.g., commands) or indicate how socially acceptable they perceived interacting with a research prototype. In the latter case, we also see a tendency to focus on "successful" evaluations, i.e., utilizing user studies to show that a specific interaction technique or research prototype meets social expectations or scores higher than a hypothesized "social acceptability level". While those summative evaluations are important to assess an interface's internal and external effects under realistic conditions, they come late in the development process where design-related social acceptability issues might be costly to resolve. In contrast, elements of ethnography, participatory design and co-creation can inform and shape designs, as illustrated by examples of elicitation studies [LLS+18], and focus groups [RB10b; WMO19]. Their more formative approach could contribute to design processes that consider social acceptability, alike user experience, from the beginning and not as an afterthought. There is a significant body of work that may serve as inspiration: participatory design methods have been comprehensively used to design sociable robots [AFC16; LŠC+17]; Social Impact Statements have been proposed as a tool to engage public participation, and to address potential negative influences of computing on society and the self-image of individuals [SR96]. Research on Value Sensitive Design proposed methods for eliciting the users' values, and for addressing the involved risk of unintentionally stating one's own (the researcher's) values, as if they had been articulated by the participants [BM12]. In summary, there is an existing knowledge base that can be adapted and made use of to address social acceptability issues in early development stages.

> **Gap 1**: To date, social acceptability is only sparsely considered during early development stages. We need to increase both user and bystander involvement and consider their views on social acceptability earlier, during phases of requirement analysis, design and prototyping.

For Diversifying the Set of Methods

There is a bias towards study types with high levels of experimenter control, i.e., experimental settings where one or more researchers are present at all times (c.f., Figure 6.2). More precisely, social acceptability issues are commonly evaluated in lab (n=14), or field experiments (n=13). Similar to Kjeldskov [KS14], we found different understandings of what constitutes a "field setting", but most works opted for relatively easy to control, confined settings with moderate throughput of passers-by, and a range of casual audiences, such as cafés, or university cafeterias. These locations, while offering a contextual (social) backdrop, provide only limited social context, e.g., in terms of user-bystander relationships, and typically cover only a section of potential usage scenarios.

In addition, survey-style research administered online or in lab/classroom settings (n=15), is highly popular. There, participants typically rate pre-defined scenarios based on visual stimuli, e.g., videos. Evaluation methods with low experimenter control, e.g., where participants exploratively try out interfaces and record experiences during everyday activities are much less common (field surveys, n=3). From our perspective, this constitutes a significant weak spot in today's HCI research on social acceptability. This also reflects in current study approaches being frequently criticized for containing an "imaginary" component, i.e., participants are asked to imagine how they would feel in a certain social situation, instead of being in that situation. Complementing controlled experiments with studies in more naturalistic, unconstrained settings would help to obtain a more comprehensive image, including unanticipated social acceptability issues.

HCI literature and practice provides a rich fund of methods, including field trials where participants act as investigators [BRS11], cultural probes [GDP99], various forms of technology probes [HHR+03] and experience sampling [HVC+15; LC14]; with collected data ranging from system logs [WCB11], user interviews, and observations or video vignettes [RCT+07]. We should make good use of it!

> **Gap 2**: To date, social acceptability is mostly evaluated in highly to moderately controlled settings. We need to show courage to tackle more naturalistic study settings and embrace mixed method approaches more, where controlled and unconstrained study settings can be complimentary.

For Closing the Loop

There is a mismatch between papers that present design strategies as results of empirical studies (n=29) and papers that employ design strategies to enhance the social acceptability of artifacts they create (n=23). In addition, only 9 of the latter works confirm the effectiveness of the employed strategies empirically. Ideally, results from the first group of papers (empirical studies on social acceptability) would inform the creation of artifacts (second group of papers). Then, created artifacts would be empirically evaluated to supplement or confirm the assumptions made based on the initial set of empirical results (in principle, what HCI and human-centered design is best at [ISO19]). Yet, in practice insights on what might improve social acceptability are often overly simplified when fed back into the creation of research prototypes: for example, subtlety (or unobtrusiveness) is often equated with going unnoticed, i.e., the use of secretive interactions or small devices. However, empirical work shows that, in fact, interactions that do provide an explanation (c.f., Williamson et al. [Wil11]) but (being subtle) do not call (negative) attention to it are likely to be better acceptable than fully hidden and unnoticeable (e.g., suspenseful) interactions [MAM+10; MCP+04]. In this context, subtlety is rather understood as non-intrusive, or non-disruptive. In addition, as noted by Pohl et al. [PMH19] there are the still to be investigated (social) costs of a secretive interaction being uncovered. Thus, creating interactions to be unnoticeable for bystanders would not be an cure-all remedy in terms of social acceptability, but would rather disregard aspects such as authenticity and honesty (justification), helpfulness (utility) and the avoidance of misinterpretations that have been shown to be relevant to social acceptability. Admittedly, there is limited knowledge how this balance between different design strategies (e.g., unobtrusiveness and candidness) can be achieved in practice, and a lack of best practices, and concrete ideas on how those design strategies could and should be implemented. These will have to be provided by future work.

> **Gap 3**: To date, there is a gap between recommendations for socially acceptable interface design based on empirical studies, and design strategies employed in the creation of prototypes. We need to bridge this gap by ideating concrete designs that fulfill these requirements, and implement, test and verify them in research prototypes.

For Measures beyond Audience & Location

There is a lack of established, standardized questionnaires that measure different facets of social acceptability. We found 15 studies that used the audience-and-location axes originally suggested by Rico and Brewster [RB09; RB10a]. While this may indicate a consensus or local standard, audience-and-location only measures social acceptability by proxy. Namely, whether user's would be willing to perform an interaction in front of a certain audience or at a certain location. This approach allows to efficiently compare different options, but lacks the ability to directly pin-point issues: design aspects that positively or negatively affect social acceptability have to be backtracked from the provided options. More precisely, the use of audience-and-location does provide a utile estimate of "total" social acceptability, but does not split up into sub-concepts. In consequence, the measure's ability to provide insights about what could be improved about a design is limited. The development and use of (validated) subscales (c.f., NASA-TLX [Har06]) to capture different aspects of the experience could aid to parse design-relevant aspects (e.g., product qualities) apart, and provide clearer staring points for improvements.

So far, work on scale development and validated measures, as e.g., by Kelly et al. [KG16], has not been re-used, evaluated, or extended by other researchers. Instead, evaluations largely depend on self-defined, custom questionnaires, which impairs comparability, and – potentially – validity. Our analysis showed that in questionnaires *social acceptability* is often described or paraphrased using a wide range of different adjectives (see Table 2.1). There, we find parallels and overlaps with existing measures and models: The set of adjectives includes aspects of perceived usefulness or perceived utility (as e.g., in TAM [Dav86]), as well as impression management and social norms (e.g., *"inappropriate"*, *"impolite"*, or *"intrusive"*). We furthermore find overlaps with the previously discussed design strategies (e.g., *"noticeable"*). Moreover, Table 2.1 illustrates how social acceptability measures fall into line with research on experienced qualities of human-machine interfaces: *"stylish"*, and *"fashionable"* relate to prior work on aesthetics and attractiveness [QT10], and notions such as *"coolness"* had been researched comprehensively in the context of user experience [STW14; BRK+16; RBK+17]. These adjectives also show parallels to the anchors used by Hassenzahl [Has04] to determine hedonic quality-identification, e.g., isolating – integrating (HQI_1), gaudy – classy (HQI_3), unpresentable – presentable (HQI_7). This illustrates that our understanding of what makes up social acceptability is still evolving. In consequence, developing a measure that reflects the construct social acceptability most adequately (i.e., has high validity) requires more than well-phrased items and suitable scales. It needs further community-wide discussion and conceptualization of social acceptability, and a better understanding of individual factors that increase and/or decrease social acceptability. Also, social acceptability should not be viewed in isolation from other qualities and affects connected to user experience. Instead, future work should aim to determine where existing constructs overlap, complement or contradict with social acceptability measures, or also strive to identify social factors that act as hygienes or motivators (c.f., Tuch and Hornbæk [TH15]). We believe that our analysis of adjectives/items that are already in use can provide a valuable starting point for these efforts.

> **Gap 4**: To date, social acceptability is mostly measured in a simplified, proxied fashion using audience and location. We need to develop measures (e.g., questionnaires) that differentiate design-relevant aspects of social acceptability, and that allow to evaluate interfaces in a more diagnostic, and problem-oriented way.

2.2.4 Summary

In this work, we reviewed papers on social acceptability in HCI. During the nearly 20 years covered by our analysis, a significant amount of contributions to a better understanding of social acceptability (and impression management) in HCI were made. However, we also identified gaps in the distribution of research approaches. In particular, ethnography, participatory design and field research in naturalistic settings without the researcher's presence were only sparsely employed. Moreover, we showed that the consideration of social acceptability, while frequently named as design goal, and also often measured and discussed, is not yet interwoven with the whole design process: results from empirical work on social acceptability do not propagate to the creation of socially acceptable designs or prototypes. With this work we motivate a stronger interlacing between empirical and artifact-creating approaches of social acceptability in HCI, and contribute to a stronger integration of social acceptability considerations during all phases of a human-centered design process. Last but not least, we discussed the current lack of established, standardized questionnaires quantifying social acceptability in a non-proxied fashion, and highlight the need to develop differentiated and truly operational measures. We hope to inspire more discussions about what constitutes social acceptability in HCI [KOW+18; KOM+19], what constructs it might comprise (e.g., "coolness" [BRK+16; RBK+17]), and how design activities can be proactively oriented toward influencing social acceptability.

2.3 Human-Centered Design as an Approach to Social Acceptability

Human-Computer Interaction (HCI) and design research are closely related. In fact, *"[d]esign-oriented HCI may conceptually be thought of as a commitment to technology and technological development that goes beyond critique"* [Fal03]. However, as the foregoing literature analysis (see Section 2.2) demonstrated, current research practice in HCI does only sparsely approach social acceptability issues from a design perspective. Instead, effects on social acceptability are empirically measured, analyzed, described, and criticized after prototype completion, e.g., to verify an interaction technique is, in addition to being usable and efficient, also socially acceptable. Moreover, social acceptability considerations do motivate design, but are often not considered at all subsequent stages of the design process, e.g., interaction techniques are designed subtle (to increase social acceptability), without further differentiation or empirically confirming the effect. In contrast, this work explores how (human-centered) design can serve as an approach to social acceptability, and how social acceptability considerations can drive the design process as a whole, specifically a human-centered design process (c.f., Figure 2.15).

2.3.1 Theoretical Foundations

This section motivates why a human-centered design process and participatory design methods, in combination with aspects from design thinking were chosen as approach for the work presented in this thesis. Essentially, all three of them are design philosophies that put the human in the center, and – drawing, among others, from the social and cognitive sciences, and engineering – are interdisciplinary in nature. While those design philosophies might in fact have more commonalities then differences, there is ongoing discussion about differentiating an ever increasing variety of both competing and complementary approaches and methods that are discussed elsewhere [San01]. Yet, there are two intersecting dimensions, illustrated by Sanders' map of design research, Figure 2.13, that allow to visualize how the individual studies presented in this thesis are situated, and how the work as a whole progressed and evolved (see Section 2.3.3). Specifically, one can distinguish between an expert mindset (left), and a participatory mindset (right). While the former focuses on designing *for people*, the latter rather takes the course of designing *with people*, where users are seen as active co-creators, and are considered true experts on their reality of life. Furthermore, one can distinguish between design-lead and research-lead approaches, where (in a broad sense) design-lead work focuses on the creation of artifacts, and research-led work on gaining insights, i.e., creating knowledge. Both dimensions are intersecting, and depending on the individual design approach and motivation, methods may shift, e.g., creating new or larger overlaps. Most importantly it has to be noted that this landscape of design disciplines is also constantly evolving, and re-negotiated. In consequence, instead of providing a complete discussion of these design philosophies, this section rather provide outline and starting points, and serves to situate the research efforts presented within this thesis as part of a larger design research landscape.

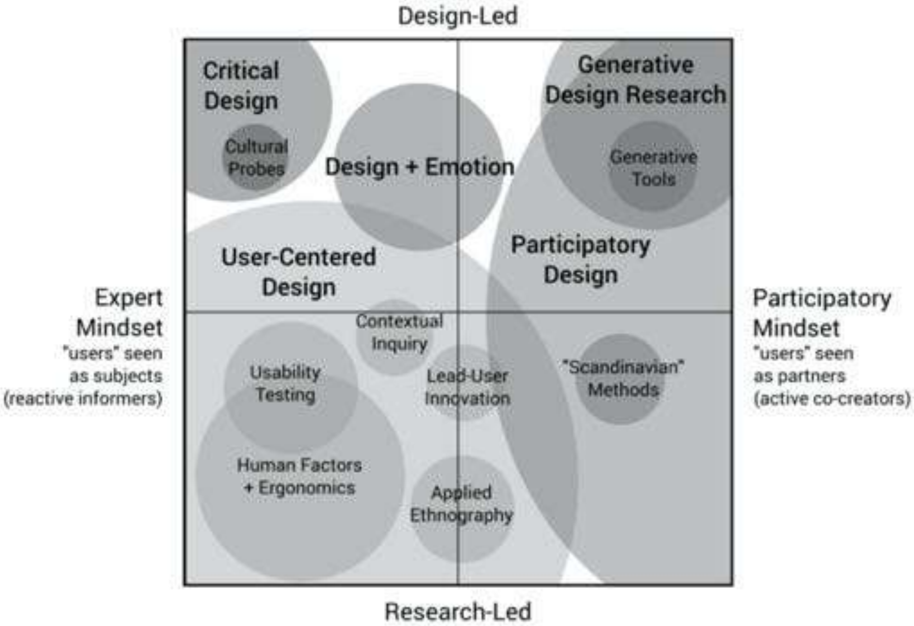


Figure 2.13: Mapping of design research types along two intersecting dimensions: expert mindset – participatory mindset (left to right), and research-led – design-led approaches (bottom to top), according to Sanders [San01].

Human-Centered Design

Human-centered (or user-centered) design[4] is characterized by putting the human in the center, by involving their perspective during all phases of a design process. One formal definition is provided by ISO 9241-210 [ISO19]:

> Human-centred design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, usability knowledge, and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance.
>
> ISO 9241-210:2010(E)

[4] Human-centered and user-centered design are often used interchangeably. However, the more general notion, human-centered design (as in the revised ISO standard [ISO19]), is commonly preferred to acknowledge the existence of additional stakeholders that are not users [Rie18; Soa16]; Thus, this thesis uses the term human-centered design to stress the inclusion of both, users and bystanders.

While ISO 9241-210 also does provide a design process model (see Figure 2.14), including the phases “Understand and Specify Context of Use”, “Specify User Requirements”, “Produce Design Solutions”, and “Evaluate Designs against Requirements”, HCI knows a variety of design process models that are human-centered [Cro08; Dix10; PRS15]. While they all share a process that starts out by understanding requirements, and then moves forward over generating designs that meet the requirements to creating prototypes while iteratively evaluating against the set of requirements, nomenclature and boundaries of phases may vary. For example, Dix et al. [Dix10] “What is wanted”, “Analysis”, “Design”, “Prototype”, “Implement & Deploy”. In the context of these design process models, design is typically understood as “Design-as-Engineering” (c.f., Wright et al. [WBM06]), where the design goal is to create a product or service that meets the user requirements. Based on an expert mindset, they often follow research-led approaches, and collect, analyze, and interpret data as part of requirements engineering [San01]. Wright et al. criticize *“[i]n this account design is seen as going from a fixed problem statement (or requirements specification), to an abstract specification of the solution that is then refined down into an actual implemented solution through a sequence of well-prescribed steps”*, and argue that this approaches neglect experiential, e.g., emotional or sensual aspects of the interaction [WBM06]. In contrast, design thinking, which can also be described through a number of similarly structured process models [Bro08; Has10; IDE15; Pan16] focuses on understanding user needs through empathy, and on creating innovation based in ideation through creativity methods that foster divergent and convergent thinking, i.e., “thinking out of the box”. Thus, its methods and tools are well suited to understand human experience, emotions, and – as relevant for social acceptability – concerns. Overall, human-centered design and design thinking are different design philosophies that share a similar, user-oriented iterative process model: understanding and observing users to determine problems, design and ideation, prototyping and testing [PM18]. In combination they allow to draw from a fund of complementary methods that allows to transfer insights from empirically measured user (or bystander) impressions into concrete design suggestions.

Participatory Design

Participatory design actively involves stakeholders, such as users, in the design process. It thereby blurs the distinction between user and designer through mutual learning, and initiates a process of co-creation and problem solving. Here, the role of the researcher transforms from being investigator to being partner and facilitator [San01]. Participatory design synergizes a variety of methods including storytelling, workshops, and the creation of artifacts [MD09]. These methods typically rely on hands-on exploration (e.g., through prototyping) and intensive face-to-face interaction. The use of physical artifacts (e.g., LEGO’s serious play[5] or Vaajakallio et al.’s Make Tools [VM07]) or prototypes as tools to visualize ideas,

[5] `https://www.lego.com/en-us/seriousplay`, accessed 2019

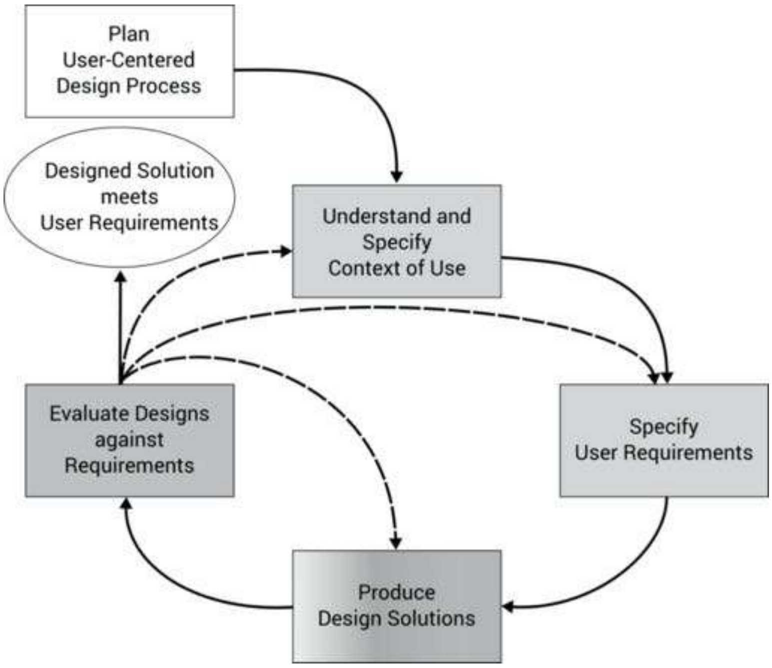


Figure 2.14: Human-centered design process as suggested by ISO 9241-210 [ISO19].

illustrate concepts, and to stimulate discussion (see also subsequent section) is one of the key characteristics of participatory design [San01].

2.3.2 Approach

The main part of this thesis is dedicated to the design of socially acceptable body-worn cameras. It investigates how human-centered design (HCD) can aid to mediate between two groups of stakeholders: users and bystanders. In other words, it explores HCD as answer to R2:

> **RQ2:** How can we meet both the user's and the bystander's needs, goals, and values while designing socially acceptable body-worn cameras?

To this aim it organizes a series of user studies conducted as part of this PhD (Chapters 3 to 6) along the five phases of an exemplary HCD process, namely (1) Observe & Understand, (2) Ideate & Design, (3) Prototype, (4) Test & Evaluate, and (5) Implement & Deploy (see Figure 2.15). The chosen approach combines a number of design-led and research-led practices (c.f. Figure 2.13) and puts the human (i.e., users and bystanders) in the center. The processes structure, with 5 phases, is based on IDEO's human-centered design process [IDE15], with elements of the Design Thinking process by Standford's d.school [Has10]. It deliberately deviates from the structure suggested by ISO 9241-210 [ISO19], and puts a stronger focus on ideation and design (phase 2) as well as prototyping (phase 3) which are contained in the standard in a more condensed way: "Produce Design Solutions" (ISO 9241-210, phase 3), c.f., Figure 2.14. It furthermore includes deployment (phase 5) as part of the design process, instead of considering it distinct from it. We motivate this through through the observation that social acceptability issues (e.g., with Google Glass) have often been uncovered only on deployment in the past. We believe that occurring issues with already deployed products or prototypes should in fact feed back into the design process.

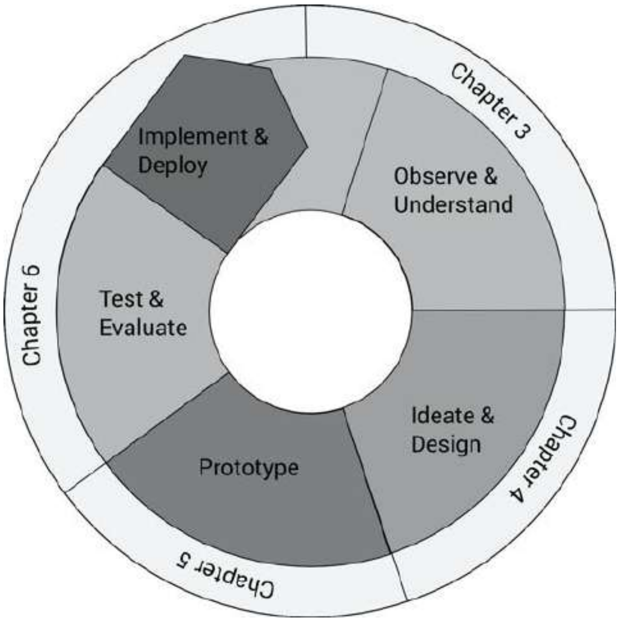


Figure 2.15: We use human-centered design (HCD) to design socially acceptable body-worn cameras. This work is organized along a HCD process, including 5 phases: *Observe & Understand* (Chapter 3), *Ideate & Design* (Chapter 4), *Prototype* (Chapter 5), *Test & Evaluate*, and *Implement & Deploy* (Chapter 6).

2.3.3 Methods

In this section we outline the methods that are used throughout this thesis. A PhD is as much about writing as about developing further as a researcher. Hence, while some of the earlier work presented in this thesis uses methods that are well established in researching of social acceptability issues with human-machine interfaces (e.g., focus groups and scenario-based surveys as suggested by Rico et al. [RB10a; RB10b]), some of the later studies are more explorative. This later choice of methods evolved based on the experience from conducting the earlier studies, and naturally progressed from viewing the participant as subject or reactive informer (Section 3.1) to viewing them as co-creator (Sections 4.1, 4.2, and 4.3), or co-investigators (Section 6.1).

Focus Groups

Starting point for the research presented in this thesis was the observation that smart glasses were ascribed a lack of social acceptability, and discussed controversially by various media outlets. We employed focus groups (Section 3.1), as this method allows for an initial exploration of a new topic through group discussions and had been successfully employed in prior work [RB10b]. In contrast to this earlier work, we did not restrict the discussion to a fixed set of interaction techniques, but structured the discussion around application scenarios of smart glasses of the participants choice and imagination. Specifically, we elicited usage situations and potential applications of smart glasses that were perceived *controversial*. Thus, at this stage, tension between dissenting or concurring opinions where essential to our research questions. Nevertheless, we also observed how participants expressed their concerns emotionally, and how they struggled to settle conflicts within the group. For follow-up research we thus decided in favor of more participatory and constructive approaches, focusing on (co-)creation instead of exchange of opinions and arguments (e.g., Sections 4.1 and 4.3).

Interviews and Surveys

Interviews and surveys are used throughout this work to collect subjective impressions and self reported user experiences. Both methods are well-established in the social and political sciences, and also in human-computer interaction [LHF17]. We conducted surveys in both, online and laboratory settings. For the survey evaluating usage scenarios of smart glasses (Sections 3.1 and 3.2) we aimed to prevent bias and to ensure that participants reported their initial impressions without consulting their peers or media outlets before answering. Thus, we conducted the survey in the more controllable, laboratory setting. As laboratory surveys are typically restricted to participants that are on-site, we intentionally switched to online surveys for some of the follow-up studies, as we required participants that were regionally distributed, rare (i.e., hard to recruit), e.g., experts on smart glasses (Section 3.2) or users of lifelogging cameras (Section 6.2). With the crowdsourcing approach presented in Section 4.2 we were furthermore able to recruit a relatively large number of participants from specific regions using quota sampling.

In the surveys, most responses were quantified using Likert or Kunin scales which allows for the *quantitative* comparison of results, and high statistical power. To complement these qualitatively, we used open ended questions, or asked for free-text explanations of provided quantitative ratings. Yet, they typically restrict the respondent to the themes covered by the questionnaire. Thus, in the evaluation of prototypes, we opted to conduct *semi-structured interviews* with open ended questions (Sections 5.2 and 6.1): in contrast to questionnaires, or fully structured interviews, their strength is to not impose ideas, or restrict the respondent to pre-defined themes.This interview method furthermore allows for a more in-depth exploration of user accounts (as the interviewer can ask the participant to elaborate on selected aspects), and helps to surface unexpected issues [LHF17]. In one instance, we decided to employ *fully structured interviews* (Section 4.3). In this study, HCI and UX experts were asked to evaluate low-fidelity artifacts against a pre-defined set of criteria: here, they were not reporting on their personal experiences, but acted as "double experts" with their expertise covering both, the evaluated interface, as well as its users, thus providing a more diagnostic survey perspective on the artifacts. The choice of fully structured interviews allowed to compare the individual experts accounts with each other in the analysis.

In short, this dissertation combines a range of survey and interviewing techniques. This method mix allows to provide strong empirical evidence through larger scale quantitative surveys, while minimizing the risk of imposing too much of the researchers own assumptions or limited views through combination with open, explorative interviewing techniques.

Co-design Workshops

Both, social acceptance (as important aspect of social life), and concerns about surreptitious recordings, are themes that study participants are familiar with. While this is advantageous for survey-style research on their opinions, it makes it more difficult to take them out of their familiar mind sets and activities and into active co-creation. Similarly, designers are often strongly rooted in established design strategies (e.g., LED status lights) when it comes to familiar hardware such as cameras. Co-design workshops are an established method in participatory design that invites both designers and non-designers to co-create ideas, concepts or designs. One of their key characteristics is that they transcend conventional working practices, by employing novel procedures or tools, which allows to breach entrenched thinking patterns [MD09]. Thus, they are a promising method to approach conflicting user and bystander needs through collaboration between designers and non-designers, were the latter become active co-creators instead of reactive informers. In this work, we report on co-design workshops with citizens, where a purposefully designed card deck is employed as facilitator to generate concepts out of existing technologies that meet the participants expectations (Section 4.1). In addition, we employed co-design methods in design sessions with experts focusing on innovating existing design strategies (Section 4.3). For the latter, we combined a structured brainstorming approach with a more designerly way of conducting idea generation through building tangible artifacts. Similar to Vaajakallio et al's. Make Tools this allowed to focus ideas, criticize concepts and speed up the HCD process [VM07].

Elicitation Studies

Systems that provide notifications or controls to bystanders need to communicate via an interface that (ideally) does not require learning or only minimal prior knowledge. This is relevant, as bystanders might encounter the system only once. In consequence, a design goal is to maximize guessability, which (in HCI) is understood as *"[t]hat quality of symbols which allows a user to access intended referents via those symbols despite a lack of knowledge of those symbols"* [WAR+05]. To this aim, this work employs a guessability-style elicitation study (Section 4.2), a method which has been successfully used in prior research, specifically to generate easy to learn and remember gesture vocabularies [PLH+14; LLS+18; SEI14; THW+15; WLB+15]. Similar to participatory approaches, it allows to involve users already in the early stages of concept development, and thus supports the consideration of social acceptability early in the design process.

Diary Studies

As outlined in Section 2.2, field surveys are an underrepresented study form in the evaluation of social acceptability, which negatively impacts ecological validity. The presented work contributes to addressing this issue, by conducing a diary study as field survey. Diary studies have been recognized a means to close the gap between observation in naturalistic settings, controlled laboratory experiments and surveys [LHF17]. They allow for the direct collection of user accounts without the researcher present in the field (i.e., in field surveys, c.f., Kjeldskov et al. [KP12]). We used this form of data collection in the field survey presented in Section 6.1, where we asked participants to document their experiences during a 2-day field text of a body-worn camera. This allows to gather (hyper-)subjective experiences during a wider range of daily activities, and include (social) settings typically neglected by other study types.

2.3.4 Summary

Human-centered design, design thinking and participatory design provide the theoretical underpinnings for the work presented in the subsequent four chapters. The work presented therein exemplifies how social acceptability can be considered as part of user experience throughout all phases of a human-centered design process, instead of only at the entry (as requirement) and in the beginning (to be verified). To this aim, we employ and combined a variety of both research-led and design-led methods (e.g., various types of user studies), and artifacts (e.g., prototypes); listed in Table 2.2. As the research approach and method themselves progressed and evolved during the design process (and PhD), studies conducted early in design process adhere more to established methods, while studies conducted later on are more explorative. Specifically, we chose to explore approaches (e.g., participatory design) and methods (e.g., co-design workshops,

	Artifact(s)	Research Method	Primary Contribution	Publication
2.2	-/-	Structured literature review (N=69)	Overview and discussion of current research practices in HCI with regard to social acceptability.	[KAB20]
3.1	84 illustrated usage scenarios.	Focus group (N=7) and lab survey (N=38)	Identification of factors influencing user attitudes towards smart glasses.	[KKM15]
3.2	-/-	Lab survey (N=118) and online survey (N=51)	Identification and ranking of factors impeding or supporting smart glasses adoption.	[KEC+17]
4.1	Deck of 34 illustrated cards	Co-design workshops as design-in-Use studies (N=26)	Card deck. Insights about expectations towards body-worn cameras in public spaces. Identification of two design challenges.	[KB19]
4.2	18 gestures as video prototypes.	Guessability-style elicitation study (N=15) and online survey (N=127)	Insights about suitability of gestures for Opt-in and Opt-out controls.	[KAC+18]
4.3	8 low-fidelity artifacts.	Co-design workshops (N=16) and fully structured interviews with experts (N=12).	3 design recommendations of status indicators for body-worn cameras.	[KWB18]
5.1	Variety of high- and low-fidelity prototypes.	Annotated portfolio	Overview and discussion of prototyping techniques for smart wearable cameras.	[unpublished]
5.2	Eye tracking-enabled, privacy-sensitive smart glasses prototype.	Dataset annotation (N=17), evaluation against ground truth. Semi-structured interviews (N=12).	Proof-of-concept: eye tracking based, automatic de- and re-activation of a head-worn camera featuring a mechanical shutter. Insights about user perception.	[SKH+19]
6.1	Chest-worn camera prototype with screen-based status indicator ("MirrorCam").	Field survey, diary study (N=9).	Assessment of bystander reactions to screen-based status indicators. Insights about social acceptability evaluation in the field.	[KWH+19]
6.2	-/-	Online survey (N=117)	Insights about the usage behavior of lifelogging camera wearers.	[KHB17]

Table 2.2: Overview of research artifacts and research methods covered by the main part of in this thesis, along with chapter, publication (where available) and primary contributions. For completeness, we also list the structured literature analysis presented in Section 2.2.

and field surveys) that had been identified as underrepresented, but promising by the analysis of existing research practice (Section 2.2). We provide a critical reflection on these methods in Chapter 7. Table 2.2 furthermore lists the main contributions of each work, along with the corresponding chapter and (where available) publication, intended to provide overview and guidance to the reader.

2.4 Summary and Conclusion

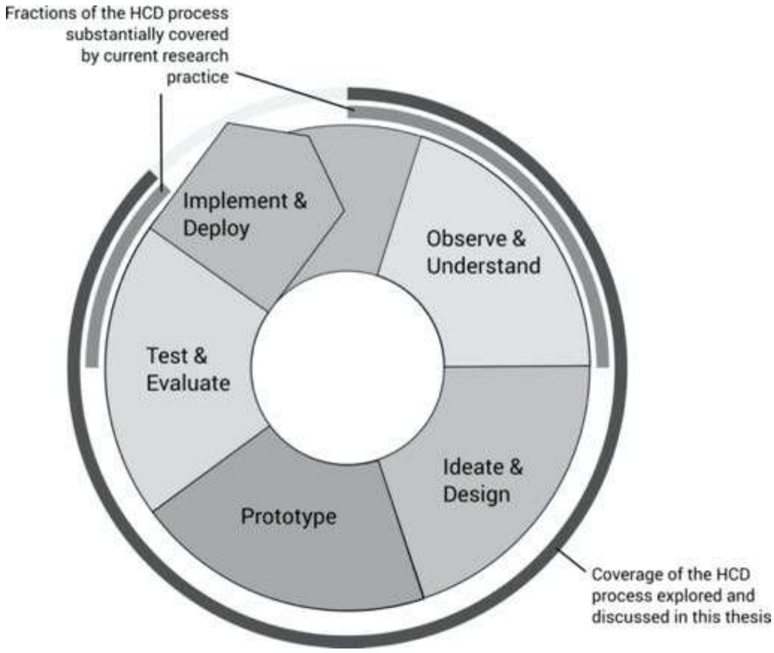


Figure 2.16: In the first part of this chapter, Section 2.2, we reviewed current practices of tackling social acceptability issues in HCI. We found the majority of reviewed prior work to cover only a fraction of the human-centered design process. In contrast, this work covers the whole HCD process.

In this chapter, we provided an inventory of current practices around social acceptability in HCI. Specifically, we looked into present definitions of *social acceptability* and *social acceptance*, as well as how both terms are commonly understood and used in HCI (RQ0). In the HCI context, we distilled an interaction model based on the user's impression management (Figure 2.2) and provided a working definition of *socially acceptable human-machine interaction* for the scope of this thesis. In addition, we conducted a structured literature analysis, and analyzed existing work in terms of methods, measures and design patterns (RQ1). We uncovered that current research practices prevalently focus on *Observing & Understanding* social acceptability issues, or complement *Test & Evaluation* of existing prototypes with (single-item) questions assessing social acceptability. Most importantly, participatory design, and approaches where users act as co-creators are underrepresented, field surveys rarely employed, and design strategies derived from empirical studies do not fully propagate into prototypes. From our perspective, these constitute significant methodical gaps. In the subsequent section (2.3.3), we outline how this thesis approaches these previously identified gaps by *considering the social acceptability of body-worn cameras at all stages of an exemplary human-centered design process.* We establish this design process as illustrated in Figures 2.15 and 2.16, and with a strong focus on the *Ideate & Design* and *Prototype* phases.

3 Understanding User Attitudes, Concerns and Expectations

Concerns about novel technologies or unfamiliar user interfaces are highly complex and may not fully generalize over device types. Otway and Winterfeldt note *"Although opposition [to novel technologies] itself is not new, the reasons for it have differed from case to case, reflecting a complex mixture of concerns related to morals, religion, political ideologies, power, economics, physical safety and psychological wellbeing"* [OvW82]. In consequence, the first step towards designing socially acceptable body-worn cameras must be to closely observe and understand the concerns involved and uncover reasons for opposition or non-usage.

In this chapter, we investigate smart glasses, head-worn computers resembling prescription glasses, that are publicly well-known due to media coverage, and may possess an "always-on" camera. Based on a focus group (N=7) and a lab survey (N=38), we show that smart glasses are expected to be always recording, and that user and bystander attitudes differ significantly. Most notably, our findings provide evidence that communicating the intention of use can increase social acceptability (Section 3.1). In addition, we evaluate whether user attitudes change over time, and gather expert opinions on factors influencing the adoption of smart glasses (Section 3.2). We identify the level of unobtrusiveness and the question to what extend social acceptability can be influenced through design as relevant further research questions for the remainder of this thesis.

With this chapter we implement HCD's *Observe & Understand* phase. From a methodical perspective, it builds upon prior work on social acceptability and user attitudes in the field of HCI. We employ different scenario depictions to evaluate smart glasses in different social contexts – a technique that is widely and successfully used in related work on the social acceptability of other types of interfaces [DW09; RB10b; RHK+07; SRR+18]. We innovate this technique by using abstract, sketched imagery to reduce bias. We further utilize user attitudes as proxy for social acceptability and measure them using a semantic differential. This provides an advantage over measuring social acceptability via audience and location (resulting in one single percental acceptability score), as it increases granularity and explanatory power.

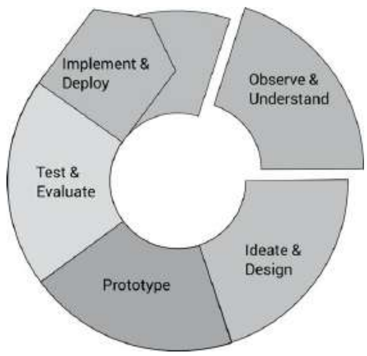


Figure 3.1: Human-centered Design Process. This chapter implements the *Observe & Understand* phase.

3.1 User Attitudes: A Proxy for Understanding Social Acceptance

One of the most widely discussed commercialization attempts of a smart glasses device was Google Glass[1]. However, when in April 2013, the first few thousand test users, called “Explorers” hit the streets, reactions – at this time channeled through various media outlets [Kel13; Art13] – were prevalently negative: smart glasses, and Google Glass in particular, were criticized for their lack of social acceptability, including their unusual looks, interference with face-to-face interactions and threat to bystander privacy.

The observation of the aforementioned critical media reactions sparked the research questions addressed by the subsequent chapter. Namely, what factors influence user attitudes towards smart glasses. In the presented research, we utilize user attitudes as a proxy to quantitatively measure social acceptance, as they allow for a more granular differentiation than the audience-and-location axes [RB09; RB10b] popularized by prior work (c.f., Section 2.2.1). The inclusion of both perspectives, user and bystander, allows concluding from user attitudes to social acceptability (c.f., Section 2.1).

3.1.1 Contributions and Related Work

This section presents a two-step user study that investigates scenario-related social acceptability of smart glasses and contrasts it with more established devices such as smart phones. Starting from a focus group discussion (N=7) we designed a scenario-based questionnaire that was filled out in a user study with 38 participants. Our study design adds a novel approach to the body of related work, by using abstract pictographs (c.f., Figure 3.2) instead of real-world footage which avoids cultural or gender bias as well as brand-specific effects. As an additional advantage this technique is well repeatable and measurements can be reproduced to map a development over time (c.f., Section 3.2).

We first present qualitative results of the focus group discussion and highlight key findings. The quantitative results of the user study are presented and linked back to the key findings from the focus group. Informed by our results, we provide quantitative measures to substantiate our implications and point out factors that can influence user attitudes. Promising application areas for smart glasses are highlighted. In particular, our research provides first indicators that the course towards professional use cases is promising. This finding aligns with Google’s decision to discontinue Google Glass in its current form[2] and to focus on “some specialized, even lucrative, uses in the workplace” [OMN14]. We conclude with incentives for design strategies to improve the social acceptability of HMDs.

[1] Today, Google’ Project Glass continues as “Glass Enterprise Edition”, `http://www.google.com/glass/`, accessed 2019

[2] BBC News, `http://www.bbc.com/news/technology-30831128`, accessed 2019

Figure 3.2: We investigate how smart glasses usage is perceived by device users as well as by their peers based on abstract, sketched scenarios. In particular, we investigate how knowledge about usage intentions (indicated as “thinking bubbles”) affects social acceptance. For illustration, the sketched depictions are shown along with possible “real-world” equivalents. However, the actual study only made use of the abstractions, to prevent e.g. cultural bias.

Related Work

Social implications of smart glasses might relate to acceptability criteria of other portable and wearable information and communication devices. In this section, we thus discuss related work in the field of mobile personal devices without limiting our review to HMDs or smart glasses (also: data glasses) in particular.

Mobile device usage in social context

Social implications of human-computer interaction (HCI) and interaction styles that are visible to the public have been particularly investigated within the context of gesture-based interaction with mobile interfaces (c.f., Section 2.2). Researchers addressed this topic aiming to determine the borderline between acceptable and unacceptable gestural interaction. Ronkainen et al. [RHK+07] investigate the user's willingness to utilize a "tap-gesture" for interaction in different situations. They presented video scenarios to their participants and asked them to imagine themselves in the videos. For our study design, however, we decided for *sketched* still images instead of videos to reduce distortion effects (e.g. gender bias) caused by the depicted actors.

Rico et al. [RB10a] conducted a comprehensive evaluation of a body- and device-based gesture vocabulary. They relate the acceptability of the used gestures to a combination of audience and location. Device perception from an observer's point of view has also been tackled by Profita et al. [PCG+13], who explore non-traditional ways of on-body input. They present a survey of third-party perceptions of user interactions with a wrist-worn interface. We present results of first- and second-person perspectives, extending available knowledge. We additionally provide qualitative and quantitative data, complementing existing research. In our user study we take into account that the two influencing factors presented by Rico et al., audience and location, are relevant to social acceptability. We thus follow a scenario-based approach, where the choice and description of scenarios comprises both place and social context. However, we do not particularly focus on gestural interaction or other input modalities. Though input styles are one important nuance of smart glasses usage in public, we decided in favor of a deductive approach to allow for a broader, more general overview. In contrast to existing work we do not limit our evaluation to the interaction with the device but also investigate effects caused by its presence alone.

Device usage in professional environments

Our expectations with regard to confidentiality are particularly high in situations where we need to unveil personal information to others that are neither family nor friends. This might, for example, include a visit to the doctor or lawyer.

DeBlasio et al. [DW09] compare traditional (analog) and technology-supported documenting methods in physician-patient interaction. They evaluate the quality of care (QoC) based on a series of questionnaires that was filled out by the participants after they had watched a video. Video-based studies allow to vividly depict realistic scenarios, including e.g. non-verbal communication. Nevertheless they also might be more prone to bias from e.g. gender, ethnical group or sympathy that might interfere with mere effects from the used technology. For this reason, we consciously decided against imagery showing real persons and for androgynous sketched still imagery.

In a more recent study, Ziefle et al. [ZR10] in 2010 investigate acceptance patterns of different concepts for e-health care systems, incl. smart mobile devices, smart clothes as well as smart environments. In [WZ12], a focus group based evaluation of the perceived privacy and security of e-health systems is presented. For a study presented by McNaney et al. [MVR+14], 4 Parkinson's patients took part in a 5-days field trial and used Google Glass during their everyday life. The authors note that patients requested full control over detailed privacy settings as well as the opportunity to create user-defined rules. They further present experiences of the participants in several public situations, such as shopping, driving and meetings with friends. While they focus on Parkinson's patients as a specific target group, the study presented here investigates the acceptability of smart glasses on a more general basis. Moreover, we consider both users and their social environment, such as e.g. friends or colleagues. In order to more closely represent a larger group, we also decided for a gender-balanced sample.

User-centered aspects of HMDs

Albeit the major gain in public attention is very recent, effects of head-mounted displays (HMDs) on user behavior have already been studied for several years. Costanza et al. [CIP+06] presented eye-q, a peripheral notification display embedded into the frame of consumer glasses. They evaluated the effectiveness of smart glasses under real-world conditions. While focusing on ecological validity and realism, they were able to show that smart glasses have the potential to be used during everyday activities, even when mobile. However, at this time (2006) the authors did not incorporate privacy or acceptability aspects into their study.

McAtamney et al. [MP06] describe the effects of an HMD on informal face-to-face communication. They present a between-subjects experiment, comparing a "wearer-condition" with a "non-wearer condition". The perceived impact of an HMD on a conversation between two participants, one of each group, is measured based on formal and informal feedback. In particular, they considered how the users' attentiveness, concentration, eye contact during conversation, and the naturalness in their behavior was perceived by themselves (as "wearer") respectively by their counterpart (as "non-wearer"). Our study design builds upon their work in terms of the comparison between the first-person view, where the interviewee is wearing the device, and the second-person view, where the interviewee is co-located with another person using the device.

In contrast to the previous work, we do not set up an artificial scenario in the lab, but present the users with a range of abstract, but realistic scenarios. By asking the users to imagine themselves in the depicted situations, we aim to rule out potential bias from the artificial situation. However, we have to acknowledge that our laboratory survey, in the style of [RHK+07], also has their limitations which we discuss at the end of this section.

Social implications of video recordings

One particularity of smart glasses is that some of them possess the ability to record video and/or audio. To novices it is often unclear if a device is able to record, if it is recording and what is captured. The way smart glasses are worn does not inherently communicate if data is captured. By contrast, users of mobile hand-held devices, such as cameras or smart phones, convey the action of recording to spectators by holding their device differently. Bohn et al. [BCL+05] note how the perception of privacy borders is influenced by our reliance on borders due to ephemeral or transitory effects. It is characteristic for human information processing that a large amount of small details passes away unnoticed, or is forgotten after a short period of time. The authors note that technologies being able to capture and prevail this kind of detailed information can potentially affect our interpersonal relationships. It is further noted that the pure (potential) existence of imagery, video or audio recordings, even if not disclosed to third-parties, makes many people feel uncomfortable and thus affects the social acceptability of such capturing devices.

More recently, these aspects have been reconsidered within the topic of *lifelogging*. Hoyle et al. [HTA+14] evaluate dedicated lifelogging devices, such as the Narrative Clip, the Autographer, and smart glasses with lifelogging functionality (c.f., Section 1.1) with regard to application scenarios, usage and sharing of the collected data as well as privacy perception. Denning et al. [DDK14] conduced "Paratyping"-style interviews with bystanders of smart glasses in cafés. They investigated in which way the interviewees expected the presence of the device to change the bystander experience. They further analyzed the factors contributing to the participants objections to being recorded and collected their ideas on imposing restrictions on recording. As one of the influencing factors the "place as a social construct" was identified. Their results add to implications obtained from previous research [NBB+11] on CCTV that found the acceptance of being recorded varying by location. With our study, we build upon these results to provide a deeper understanding of space- and context-based perception of smart glasses usage in public.

3.1.2 Focus Group

We conducted an initial focus group discussion to better understand in which occasions, situations and locations the usage of smart glasses is (in-)appropriate or discussed controversially. In particular, we aimed to identify reasons for positive and negative reactions to smart glasses.

Seven participants, aged between 25 to 37 (M=32, SD=4), took part in a 40 min. focus group discussion. The participants (4f, 3m, 0d) were researchers with different areas of expertise. None of them had a background in computing science or HCI. They were recruited from two universities, unequal to the authors' affiliation. Two of them were experienced with smart glasses in a broad sense, i.e. they had tried HMDs once to a few times. They did not consider themselves as regular users. The remaining 5 had never used or tried such devices.

Method

The focus group discussion took place in a seminar room at TU Munich. At first, the participants were asked to note down situations, in which smart glasses are already used or in which they could imagine that smart glasses will be used in the future. The participants had 15 min. time to reflect and note each item on a separate card. In a second step, they were asked to group these situations into 3 categories using 3 separate pin boards based on an open discussion of 25 min.

Inappropriate the participants agreed concordantly that in these situations the usage of smart glasses is not acceptable or should be restricted. (**I**nappropriate **S**cenario, **IS**)

Controversial the participants were indecisive or disagreed on whether smart glasses usage is socially acceptable or unacceptable in these situations. (**C**ontroversial **S**cenario, **CS**)

Appropriate the participants agreed concordantly that in these situations the usage of smart glasses is both reasonable and acceptable. (**A**ppropriate **S**cenario, **AS**)

The participants were served with beverages and sweet buns. They did not receive monetary compensation.

Discussed Items

The items named by the focus group indicate that the usage of smart glasses in social contexts is perceived as highly debatable. Participants discussed a variety of items, including potential usage situations as well as roughly defined applications on smart glasses. For analysis, duplicates were removed and items were summarized.

In summary, 26 different items were identified, of which 9 situations and 5 applications (cf. Table 3.1) were rated as *controversial* and in parts discussed emotionally. In 7 of the discussed situations smart glasses usage was rated as *inappropriate*. On the one hand these included occasions where technology use is prohibited or restricted per se, such as “courtrooms” (IS1), “sauna/pool” (IS2), “church/synagogue” (IS3) as well as descriptions such as “on a date/rendez-vous” (IS4) or “during confidential meetings” (IS5), where social norms apply. While we assume these not to be very surprising, on the other hand also statements such as “record s/o without consent” (IS6), “anywhere before everyone viewed agreed”

(IS7) were documented as inappropriate. These nominations reflect our initial impressions that smart glasses usage is perceived as a serious threat to privacy. Though legislation varies between regions (described in detail in [WSB+14]), the discussion on smart glasses indicates that there might be a wish for more comprehensive regulations for public video and audio recordings. The flag *appropriate* was assigned to a range of prevalent non-public occupations such as "cooking" (AS1) or "relaxing at home" (AS2) as well as (semi-)professional activities such as "training observation" (AS3), "skiing-/biking goggles" (AS4) and "surgery/medical applications" (AS5).

A summary of discussed *controversial* situations (CS) and applications (CA) is listed in Table 3.1. To allow for an in-depth evaluation of the named situations and applications, we conducted a further user study which we describe in the subsequent chapter.

Some items were omitted for the user study and thus shall be briefly discussed here. The statement "gaming" (CA5) and "when children are involved" (CS4) were discussed with regard to their media educational aspects. (Ir)responsible technology usage together with and by children was named as reason to classify the latter as *controversial.* Gaming was critically discussed in the context of addictive behavior. P6 noted *"[...] of course it is your choice. But I think sometimes when I see the behavior with smart phones, it is not a choice anymore, it is like [addiction]?* Both items are traditionally covered in the broad research areas of media education and communication science and out of the scope of the current work. Furthermore, the category "cultural events" (CS7), such as "concert", "vernissage" or "museum" was not re-evaluated during the user study. We made the decision to omit these items, as the limiting regulations in the respective context are (as also noted by Participant 3, (P3) and (P4)) based on copy right law.

Key Insights

Social context matters. The suggested situations were discussed more critically by the participants if they involved interpersonal communication. Situations where only or prevalently the device user was involved, e.g. home entertainment applications or professional occupations such as surgery and manufacturing, were rated less severe. Those were assigned to the "appropriate" category in most cases. Smart glasses usage during personal conversations was considered "rude". However, participants also claimed that the usage of smart glasses during interpersonal interactions was not perceived differently than smart phone or other device usage.

Freedom of choice versus privacy protection is controversial. As a general tendency, we noted that the participants' attitudes towards a usage situation changed depending on whether they imagined themselves as the person using a device, their conversation partners, or third-parties. On the one hand, the participants claimed the freedom to use whatever device they want, as long as

Controversial Situations	
CS1:	during personal interactions
CS2:	business meetings
CS3:	walking in urban areas
CS4:	when children are involved
CS5:	walking outside of urban areas
CS6:	teaching situations
CS7:	cultural events
CS8:	working environments
CS9:	while driving

Controversial Applications	
CA1:	recording of images, video, audio
CA1:	navigation
CA2:	reading news, messages
CA3:	sightseeing
CA4:	gaming

Table 3.1: Distinct 9 situations and 5 applications named and classified as *controversial* during the focus group discussion. For analysis, duplicates were removed and items were summarized.

they do not interfere with anyone else. Some participants even felt the necessity to advocate their free choice of device usage: *"You are trying to forbid me my freedom of holding my mobile phone like this. I don't interfere with you at all. If you don't like me sitting like this, that's your problem. Not mine"* (P1). On the other hand, they also expressed that they are likely to feel intimidated when others in their proximity use devices such as smart glasses. Some participants requested to forbid the usage of smart glasses in public spaces.

More established devices are perceived differently. The participants were more sensitive to privacy violations by smart glasses than to the same inappropriate behaviors using established devices. However, P1 noted, "*[...] it's forbidden to record certain stuff, and it's forbidden with [smart glasses] in the same way as with other UIs [user interfaces]"*. Denning et al. [DDK14] investigated the reasons behind that effect by asking "Do you think recording with those glasses is similar or different to recording with a cell phone? Why?". A similar effect has been reported as the so-called *status quo bias* [SZ88].

Knowledge about performed actions is relevant. The participants expressed the desire to know what the person facing them is using her device for. Often, the inherent form factor of devices such as smart phones already communicates a type of action. Actions such as e.g. "taking a video" or "reading" could be inferred from the device posture or from the gaze direction of its owner. However, smart glasses do have different affordances. In this case, the participants were unsure how the type of action performed by the owner can be deduced. We assume that this is both due to the fact that the participants were not experienced with others using smart glasses and as a consequence of the characteristic form factor of these devices.

Smart glasses are expected to be always recording. Similarly, we observed that some of our participants assumed that smart glasses are inherently recording. P2 stated *"If you wear [smart glasses] that is similar to that you are recording. I think, you must not use them. You must ask everyone before"*. The participants also stated that LED lights indicating whether a device is recording, were either not perceived at all or did not entirely eliminate their concerns.

Summary

During the focus group, we gathered a list of 9 situations and 5 applications that were identified as controversial. The focus group indicated that user attitudes towards smart glasses usage are more critical than towards the usage of other portable devices. We noted that smart glasses usage might be perceived differently from a first-person (the user's) point of view than from a second-person perspective. This finding aligns with the effect described by Palen et al. [PSY00], where they found a notable discrepancy in their participants' perception of the social appropriateness of mobile phone usage, when comparing their initial attitudes to their opinions in the first 6 weeks after they became active mobile phone users. Moreover, we found that knowledge about actions or intentions of device usage affects its acceptance. Following a two-step approach, those aspects were reconsidered during the user study.

3.1.3 User Study

Under consideration of the focus group's feedback we conducted a quantitative user study. In contrast to the initial focus group discussion, we decided to base the design of our second study on predefined, but roughly sketched scenarios that leave room for individual associations (cf. Figure 3.2). We base our choice of scenarios upon one of the focus group's essences – "social context matters" – and expand our focus to social acceptability. We therefore refer to the definition and survey of social acceptability in HCI in Chapter 2. Here, we go into detail on the choice of scenarios and the design of the questionnaire. Finally, selected results and key findings are highlighted.

Method

We evaluated the designed scenarios with 38 participants (22m, 16f, 0d). The participants were aged 18 to 38 (M=23, SD=4). They were recruited via a local recruitment platform based on a random selection of a gender-balanced subsample

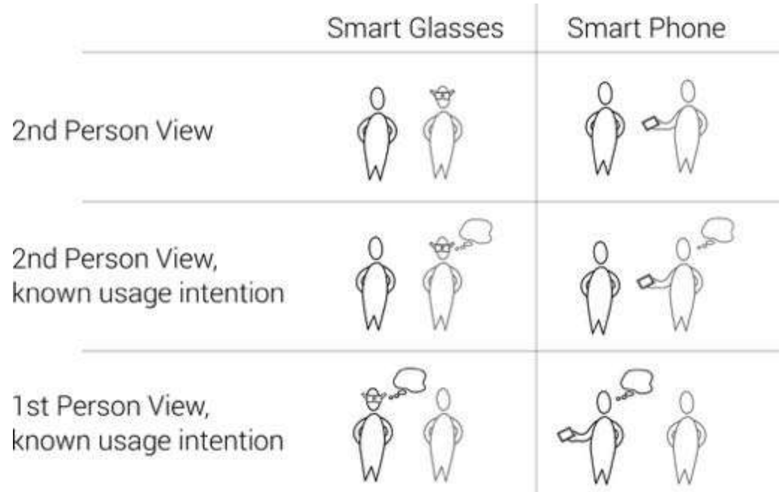


Figure 3.3: Each basis scenario was altered according to the independent variables. The user is depicted with the device (orange). Participants were instructed to imagine themselves as the person marked through black outlines; either as user (1st person view) or bystander (2nd person view). Usage intentions are indicated through "thinking bubbles".

of the platform's database (N=1471). Only two of the participants had experiences with smart glasses; all other participants stated to have no such experiences. The study was conducted in a controlled lab environment at our institute. Participants registered for individual time slots of 1 hour each. In order to minimize effects of social desirability or social approval, the questionnaire was filled in by each participant in private using a desktop computer located in a separate polling booth. In order to gather unbiased and spontaneous reactions, the participants where not informed about the study's topic during the registration process. They were briefed on the purpose of the study in the beginning of their lab session. During the study, the participants were shown different sketched illustrations of usage scenarios, one at a time. Each scenario was represented by an illustration and two to three neutral descriptive sentences. An overview of all scenarios is provided in Appendix B.

Following a between-subjects design, the participants were assigned to two different groups by lottery draw. Half of the participants were told what purpose the depicted person was using a device for, i.e. they were allowed to "read the thoughts" of the person using the device. In contrast, the other half did not receive any additional information, i.e. they had to rely on the way the device was held by the person depicted in the scenario and guess the action. They were served with cold beverages and sweets and received an appropriate monetary compensation following the recruitment platform's convention, i.e. 10 Euro/hour. The compensation was disbursed after the study in a separate room and by personnel different from the experimenter.

Choice of Scenarios and Study Design

Based on the situations that were rated as *controversial* during the focus group discussion we created a catalog of illustrations of 14 different scenarios (in total 84 different variations). A summary of all scenarios is included in Appendix B. To allow for a detailed evaluation, the scenarios were altered in two ways. From each basis scenario, several illustrations were derived, by alternating the kind of device (smart glasses or smart phone) and the person using the device (*first-person* condition, *second-person* condition). The derivation of 6 variants based on one example scenario is illustrated in Figure 3.3. The first-person view is not subdivided as it always includes an indicator for the performed actions. This was decided, as in a realistic scenario the device user usually is aware of the intention of her actions. The scenarios were assigned to 3 main categories:

1. **Interpersonal conversations:** conversational situations where two or more actors are involved, different topics of conversation are depicted using symbols. [**4 scenarios, 24 variations**]
2. **(Semi-)public spaces:** situations in public where strangers are encountered as well as characteristic situations while driving. [**5 scenarios, 30 variations**]
3. **Work environments:** professional situations that involve a spectator (e.g. as patient, customer or an audience). Scenarios only involving a professional user and a device were not considered. Illustrations including a notebook were added for baseline comparison. [**5 scenarios, 30 variations**]

All in all, we created 84 different illustrations, of which 18 are shown from a first person's view. Two-times 38 illustrations are shown from a second person's view, either with or without depictions of the intention of device usage. Each participant rated *all first-person perspectives*, and one of the aforementioned sets-of-38, according to her assignment to the "thought-reader" or "non-thought-reader" condition in the between-groups design. Overall, 56 illustrations were rated by each participant in randomized order, taking approx. 30 mins.

To ensure that the used picture vocabulary is clear and comprehensible for a general audience, we based the sketches on the *bikablo visual dictionary*[3]. Persons are depicted androgynous, i.e. they are not explicitly male or female. This aims to support the interviewee in putting themselves in the position of the shown actor.

Design of the Questionnaire

The questionnaire started with a brief section assessing the technology affinity of the interviewee on a 5-point Likert Scale. The eight items were chosen from the standardized and verified questionnaire TA-EG [KGC+09]. Comprising 4

[3] Bikablo Visual Dictionary. `http://www.bikablo.com`, accessed 2019

sub-scales, namely enthusiasm for technology, positive and negative consequences as well as expertise, we found the TA-EG suitable to provide a baseline for user attitudes towards technology. The scenarios were rated based on a semantic differential, in order to compare the effect of the scenarios' alternations on a numerical basis. Semantic differentials are a well-understood and established method to measure emotional responses in psychology and in HCI [AM09; HPB+00]. The adjectives used for our investigation were justified by related work and deliberately chosen based on recent research. Our choice is based on work of Walter et al. [WWB+14], who explicitly focus on scenarios involving human-machine interactions and human-human interactions. Table 3.2 lists the semantic differential's pairs of opposites.

negative connotation	positive connotation
tense	serene
threatened	safe
unsure	self-confident
observed	unobserved
skeptic	outgoing

Table 3.2: Pairs of opposites used to create the semantic differential. Positive connotations are listed on the right, negative connotations on the left.

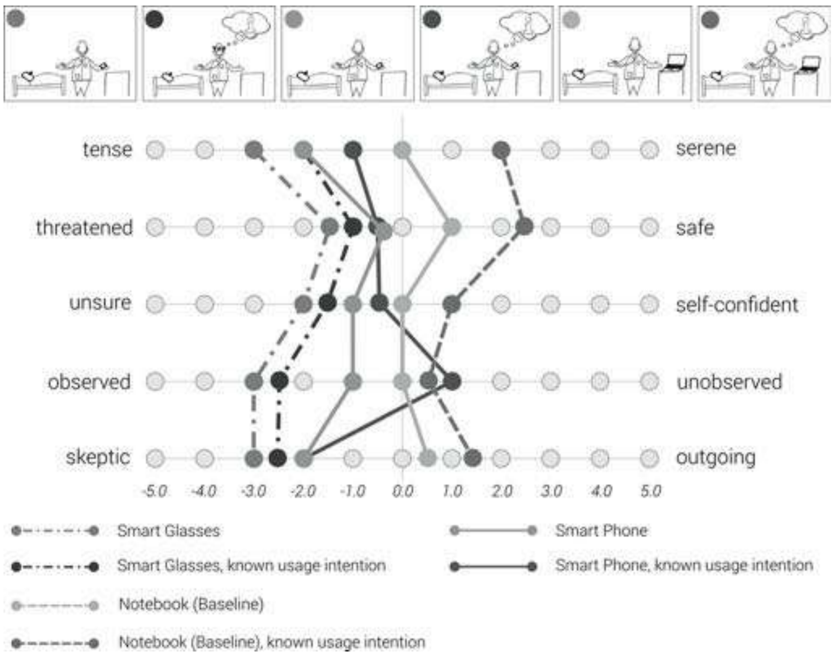
We asked the participants to indicate their subjective perception of the scenario based on pairs of opposites using a slider on the screen below the illustration. The slider range comprises -5 to +5 (resolution of 1.0) and corresponds to a 11-point Likert Scale; resulting in ordinal scaled data [MKS+13].

Results

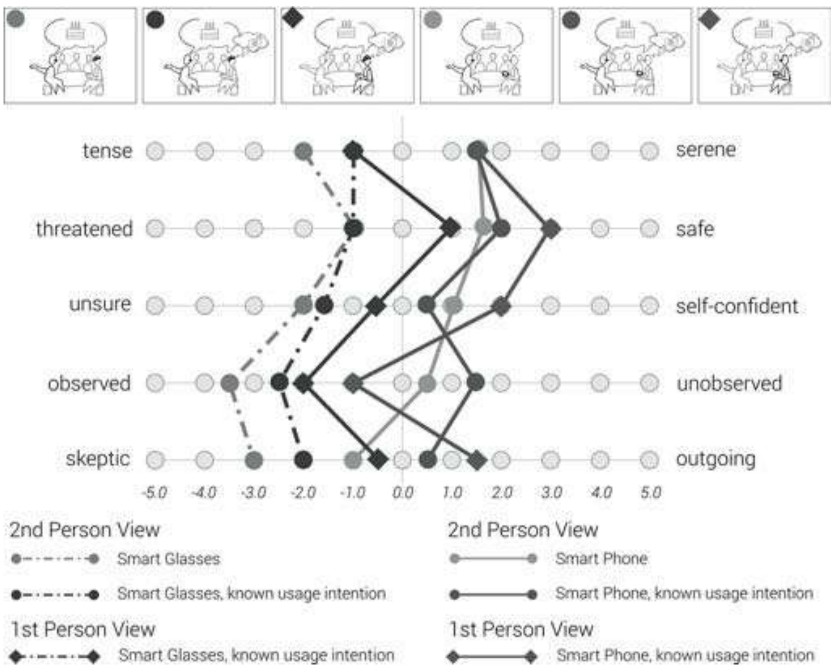
In the following, selected results of the user study are discussed and linked back to the initial hypotheses obtained from the focus group discussion and related work.

More established devices are perceived differently.

The analysis of the focus group discussion indicated that more established devices, such as smart phones, and smart glasses are perceived differently. The results of the user study support those initial findings. We computed average scores from the mean values of the semantic differential. Scenarios where smart glasses were used, achieved lower average scores (min. avg. score: -3.1, max. avg. score: 0.4, M=-0.99, SD=1.63) than scenarios where smart phones usage was depicted (min. avg. score: -1.4, max. avg. score: 3.8, M=2.68, SD=2.86). The largest differences were found for public transport (see Figure 3.5) and conversational scenarios (see

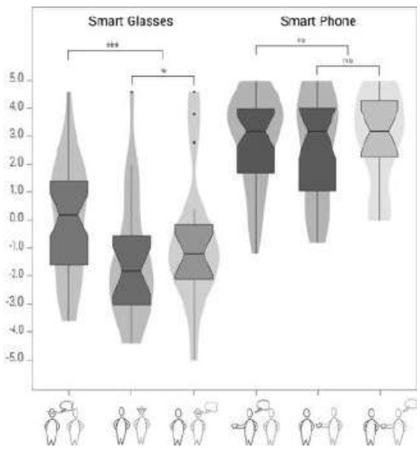


(a) Detailed results of the semantic differential for conversational scenario. Work scenarios include only the 2nd person view. Here, a notebook condition is used as baseline comparison.



(b) Detailed results of the semantic differential for conversational scenario. Conversational scenarios include both, the 1st person view, and the 2nd person view, but no notebook condition.

Figure 3.4: Aggregated results (median ratings per pair of adjectives) of two scenarios: work scenario (top, medical) and conversational scenario (bottom, family group conversation) illustrating the use of the semantic differential.



(a) Violin plot of the "subway" scenario. On a Likert scale from -5 to 5, smart glasses (the three plots left) are rated more negatively than smart phones (the three plots right).

(b) Participants were provided with an illustration, and a description. Here: "You are taking the subway. The passenger just across from you is using smart glasses to read a news feed".

Figure 3.5: More established devices are perceived more positively. In the "subway" scenario (right), smart phone usage, which is common practice, was rated positively, whereas smart glasses usage, which is unfamiliar, was rated more negatively.

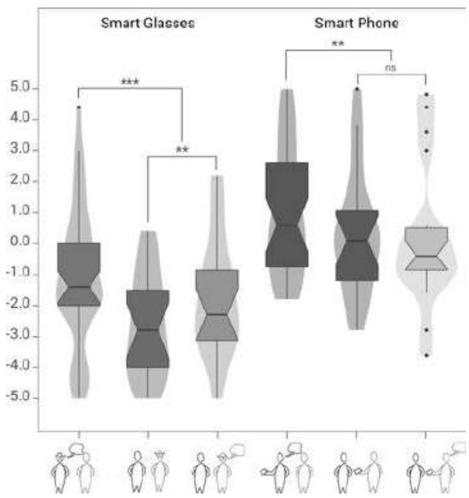
Figure 3.6). The differences we found were significant[4] for all scenarios.

In Figure 3.4 detailed results of the semantic differential are shown for a medical (work) scenario and a conversational scenario. Smart glasses and smart phone conditions are depicted along with the notebook condition, which is used as baseline comparison. Both notebook ($p < 0.001$) and smart phone ($p < 0.001$) conditions achieve significantly higher scores than the smart glasses condition. Thus we cannot confirm the results in [DW09], where a desktop computer condition was rated significantly worse than wearable conditions.

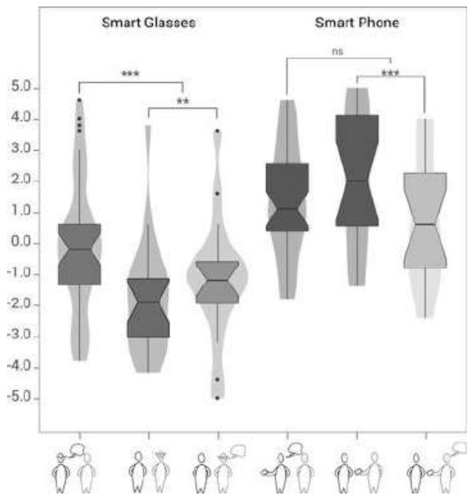
Women are more likely to express negative feelings

We found significant differences between male and female participants for 18 of the 22 evaluated scenario variations with smart glasses. 16 of the 22 evaluated scenarios, were rated significantly (all $p < 0.05$, $p \in [0.0001, 0.03]$) more negative by female participants. In contrast, the two 2nd person scenarios involving smart glasses usage during driving, were judged significantly more negative by our male participants. Despite this exception, we find in summary that female participants were more likely to express negative feelings towards scenarios with smart glasses than male participants. A colloquial explanation for similar effects in the past has been to assume that women are less enthusiastic about technology and less

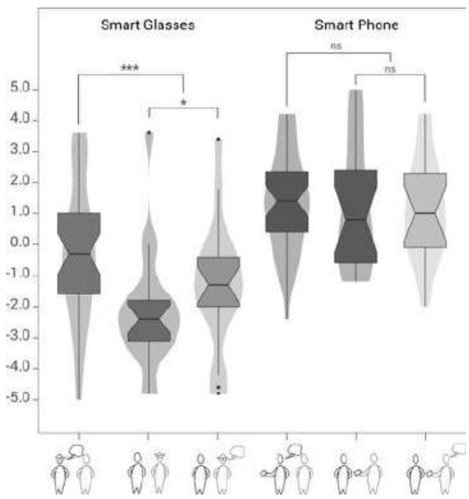
[4] The p-values for the within-subjects comparisons were obtained from the *Wilcoxon Signed Rank Test* resp. the *Friedmann Test*



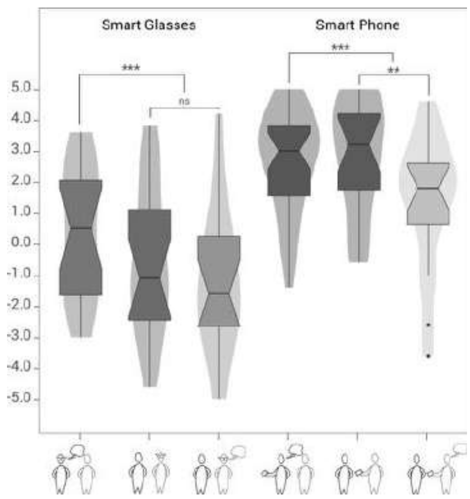
(a) Conversational scenario 1: Personal one-on-one conversation (date).



(b) Conversational scenario 2: Business one-on-one conversation.



(c) Conversational scenario 3: Business group conversation (business meeting).



(d) Conversational scenario 4: Personal group conversation (family gathering).

Figure 3.6: Detailed results for all conversational scenarios as violin plots. Scenarios are alternated in terms of the type of device (left: smart glasses, right: smart phone). We display the alteration of the device user (black, left: the interviewee and grayed out, right: a second person) and the visibility of actions performed with the device (indicated by "thinking bubbles") as pictographs on the x-axis. The y-axis denotes the scores obtained from the semantic differential: positive user attitudes are >0, negative attitudes are <0. We indicate statistical significance from highly significant (***, $p < 0.001$) to significant (*, $p < 0.05$), with ns for no significance.

likely to be early-adopters. This is also reflected by the TA-EG, where our female participants were significantly more likely to approve the items of the *enthusiasm for technology*. However, the TA-EG questionnaire did not yield significant (all $p > 0.1$) differences between male and female participants regarding *positive and negative consequences of technology usage*. We think that the latter explanation is only covering one aspect of the described effect: In contrast to the scenarios involving smart glasses, only 8 out of 22 depictions with smart phones show significant differences between male and female participants. Despite the lower enthusiasm for technology, also a second effect might be relevant: we noted earlier that smart glasses are expected to be always recording. Hypothesizing that the fear of and experience with being surreptitiously watched varies between genders might add up to that conclusion (c.f., Hirst and Schwabenland [HS18]).

Freedom of choice versus privacy protection is controversial.

The focus group discussion implicated that the usage of smart glasses is perceived more positively from a first-person perspective than when the device is used by a second person. The findings from the user study support this hypothesis partially. We found significant[5] differences for all conversational scenarios. The one-to-one business conversation was rated with a score of -0.6 from the first-person perspective and a score of -2.2 from a second-person point of view ($p < 0.001$). However, for scenarios involving random encounters in public environments, e.g. in the subway or on the street, no significant differences were found. A possible explanation might be the desire for social approval. To humans it is more important to receive positive feedback and appreciation from a person that they are personally connected with (such as e.g. a conversational partner) than e.g. from random passers-by. Nevertheless, from the *Pearson product-moment correlation coefficient (r)*, an at least moderate positive correlation ($0.20 < r(188) < 0.39$, $p < 0.01$) between the rating of the *first-person* condition and the *second-person* condition, can be reported for all scenarios. A strong correlation ($r(188) > 0.4$, $p < 0.001$) was found for 8 of the 18 pairs of scenarios. This means that participants who rated others wearing smart glasses more harshly, were also indicating more negative feelings in scenarios where they were using the device themselves.

Knowledge about performed actions is relevant.

The focus group's participants considered it relevant to have a rough idea of someone else's actions with a mobile device. To provide further evidence for this claim, we performed a between-subject test with two groups in this user study. Symbolic and textual cues indicating the usage goal were given to one group. In contrast, the other group was only told which device was used in which situation. Significant differences between those two groups were found for 3 of 4 conversational scenarios and 2 of 5 scenarios in public spaces.

[5] P-values for the between-subjects comparison determined using a *Mann-Whitney Rank Test*.

We found no significant differences (all $p > 0.05$, $p \in [0.1, 0.4]$) for work environments. It could be concluded that smart glasses that are used in work environments are inherently perceived as professional tools. Hence, additional markers indicating the purpose of their usage are not necessarily required. On the other hand, these findings also implicate that for applications designed to be used in private social contexts, indicators of their purpose of use can be one way to improve their acceptability. Putative knowledge about the purpose of device usage allows the observer to feel more secure. This assumption is also concordant with research on cognitive bias such as for example the *illusion of control* [Tho99]. As smart glasses are perceived as a threat to privacy, this aspect might be one key towards improving their acceptance.

3.1.4 Discussion

This section names and discusses implications and limitations of the presented research. We critically address several aspects of methodology and results. Concluding from the discussed aspects we then develop strategies for future work in this area. We provide examples for follow-up studies and possibilities for technology improvements.

Design Incentives and Future Directions

This section revisits some of the results of our studies and highlights selected potentials that might motivate future design decisions. Based on qualitative and quantitative results of our study, we highlight initial indicators for best practices in smart glasses design. We found that, to increase the prospects of head-worn devices to become part of our everyday lives, they would need to match the following characteristics.

Be task focused. Results of our user study provide indicators that smart glasses in working scenarios are already perceived as professional tools. Future designs could make use of this by focusing on clear, task-oriented usages. During our focus group discussion, “surgery” and “skiing/biking” were named as possible task-specific use cases, and also as *appropriate* use cases. In consequence, a key to improving acceptance might be to design smart glasses as dedicated aid to specific professional (e.g. manufacturing or surgery) or semi-professional tasks (e.g. skiing) instead of designing all-purpose smart glasses.

Follow a least capabilities principle. From the focus group we learned that bystanders are likely to assume that smart glasses are always recording, which negatively affects their social acceptance. We thus propose a simple least capabilities principle: If the use case does not require a camera/microphone/display, just do not add one. This could be supported by a modular design approach, such as

Project Ara for smart phones[6]. One could even imagine to design interchangeable modules that could be attached and detached depending on the current use case.

Communicate the intention of use. Many of our current devices, such as smart phones, have an inherent form factor that already communicates a type of action. Actions such as "taking a video" or "reading" could be inferred from the device posture or from the gaze direction of its owner. However, smart glasses have different affordances. Our work's results were able to quantitatively demonstrate that knowledge about the intention of device usage can significantly affect user attitudes. This complements and extends qualitative findings currently available in literature. P2 of our focus group noted, *"[...] If you go around with Google Glasses, there should be a rule to indicate whether the system is working"*. Our user study confirmed, that knowledge about the actions performed with a device are particularly relevant to reduce objections. We already find humorous examples of self-made or 3D-printed solutions, such as "Glass Privacy Cover"[7]. Future work hence might aim to find more appropriate and intuitive ways to communicate usage intentions to third-parties.

Provide subtle, but clear interactions. Another solution and key aspect in designing interaction styles for smart glasses will be to find the appropriate degree of unobtrusiveness: if the interaction is too obtrusive or unnatural, the device user is likely to feel uncomfortable or intimidated (cf., Williamson et al. [WBV13]). On the other hand, unobtrusive interactions that do not convey the intention of device usage negatively affect social acceptance. A possible approach could be to investigate suitable metaphors. One possible, yet to evaluate example, could be the "opera glasses"/lorgnette-metaphor: the smart glasses would only allow to record video with a finger pressed to the frame (telling "I can see you..."). Future research could explore metaphors that allow for more acceptable interactions with existing hardware.

Limitations

To substantiate our conclusions, this section points out to which scope they are applicable and highlights their limitations. Designing a practicable survey requires to limit the overall time spent by a participant to complete the questionnaire to a reasonable amount. For this reason, we had to confine the scope of scenarios, first to social contexts, secondly to those that emerged as particular *controversial* during the focus group discussion. We further excluded scenarios involving children from our investigation. Thus, our results might not be applicable to other contexts, where specific factors, such as e.g. productivity or safety, might be more relevant. The relationship between the user and other present people (e.g.

[6] As of 2019 Project Ara (`http://www.projectara.com/`) had been discontinued. Project information including an archived version of the original web presence is available from `https://en.wikipedia.org/wiki/Project_Ara`, accessed 2019

[7] J. Biehler, Glass Privacy Cover, `https://www.thingiverse.com/thing:182763`, accessed 2019

instructor-scholar) was tackled, but not evaluated in detail. We acknowledge that – due to the finite amount of scenarios – there are many other situations with and without social context that have not been evaluated. We further acknowledge that the evaluated selection of scenarios is rather typical for Europe or the US and will most probably not be representative e.g. for MEA or APAC countries.

3.1.5 Summary

In this section we presented results of a scenario-based evaluation of smart glasses usage. Starting from a two-step approach, including a focus group discussion and a user study, we identified factors that positively and negatively influence user attitudes. We found, that smart glasses usage is perceived critically, but more positively from a first-person perspective (the user themselves) than from a second-person perspective. However, one might argue that the negative attitude towards smart glasses is related to the unfamiliarity of the device. Similar to the so-called "Walkman Effect" of 1984 [Hos84], this negative attitude might diminish over time. Interesting developments could be discovered by repeating this study at regular intervals or in different regions. Moreover, we derived design implications for future head-worn devices. Our research provides initial indicators for best practices in smart glasses design. We found that, to evolve into a product that clicks with users, head-worn devices would need to *be task focused*, *communicate the intention of use*, and *follow a least capabilities principle.*

3.2 Factors Impeding the Acceptance of Smart Glasses

Over the years, observations of technology adoption have shown that technical innovation often triggers fear, anxiety and objections [CM15]. However, initial indignations were also noted to often fade away. Both Hosokawa's "Walkman Effect" [Hos84] and the dissemination of consumer photography [Ber15] show how users of a mobile gadget can attract criticism and be accused of rudeness and disrespect of other people's privacy. Albeit, the Walkman, which was predecessor to a whole line of portable music devices, including the iPod, and portable (digital) cameras have found their way into our daily life.

3.2.1 Contributions and Related Work

This work investigates whether the "Walkman Effect" also applies to smart glasses, which we define as class of mono- or binocular head-worn displays that resemble prescription glasses, not limited to a specific device type or brand. Up to now the roles of familiarization over time and social acceptability are not clear, as smart glasses are different from earlier innovations. They differ in terms of form factor and display paradigm, but also in terms of (online) media coverage and exposure [RR16]: with only 1% of smart glasses owners in the US[8], the majority of potential users did not come in contact with actual devices, before they became aware of the publicly hyped discussion. This section looks at factors that are decelerating smart glasses acceptance from both, a retrospective (user study-based) and a prospective (expert survey-based) point of view.

Related Work

We outline theories and models of two relevant research areas: the dissemination of a technology from niche applications into society and the adoption of technology by individuals.

Technology Diffusion into Society

Van Mensvoort's "Pyramid of Technology" [van13] describes the different levels a technology attains from being envisioned (level 1) until becoming naturalized (level 7) and omnipresent. Characteristically, many technologies only climb the lower half of the pyramid, i.e. *applied* (level 3) or *accepted* (level 4), before they stabilize or are replaced by newer technologies. Innovation diffusion models [Rog10] illustrate that initial judgments, though made without any prolonged use of the technology, serve as a filter and either result in non-appropriation or adoption of a new technology. In consequence, initial user attitudes, as we assessed in our case study, are crucial for the success or failure of a particular technology's adoption.

This work focuses on the transition (or "disruption") between an *applied* and an *accepted* technology, c.f. Cisco's Media Disruption Map[9]. Smart glasses have attained the *applied* level by taking the step out of the lab. Our work looks closely on the preconditions of an alternation to an *accepted* technology, i.e., to being "part of our daily life" [van13], which we consider achieved if a society's majority has moved from being *excluded* on to being *core* or *peripheral* users [Sel03].

Technology Adoption by Individuals

Davis' well-known Technology Acceptance Model (TAM) [Dav86] defines the adoption of new technologies by individuals based on two main factors: usefulness and perceived ease-of-use. Derivative models add subjective norms and social influence [MG99; VM00], and share the assumption that individuals tend to consult their social network in order to reduce anxiety towards an innovation [KSC99]. Building upon this theoretical ground work, we investigate the characteristics of smart glasses adoption, particularly looking into cross-relationships of different factors and provide a device-specific ranking of relevant factors.

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[8] Vision Voice Newsletter. Google Glass Awareness in the US, `http://east.visionexpo.com/Press/Vision-Voice-Newsletter/Google-Glass-Awareness-in-the-US/`, accessed 2019

[9] GDI. From Innovation to Disruption, `http://www.gdi.ch/i2d/index.html`, accessed 2019

An in-depth investigation of smart watch adoption in the context of TAM has been presented by Kim et al. [Kim15]. They investigate "subcultural appeal", i.e. smart watches being a fashion statement, in addition to traditional TAM patterns. Buenaflor et al. [BK13] assess human factors, including social, physical and demographic aspects of the acceptance of wearable computing devices. A stream of research conducted by Rauschnabel et al. takes a managerial perspective on smart glasses adoption. They look into social norms and functional benefits [RBI15], fashion [RR16] as well as perceived usefulness, ease-of use and both user's and bystander's privacy [RHH^{+}16]. While prior work determined factors that influence smart glasses adoption, our work goes further and estimates the precedence of improvements based on expert opinions.

Contributions

We retrospectively discuss the adoption of smart glasses to date, based on a multiple-year case study (N=118) and investigate prognoses from a survey among 51 experts on smart glasses, HCI and technology adoption from industry and academia. Our research questions are: (A) *Can an alteration of user attitudes similar to the "Walkman Effect" be already observed for smart glasses?*, (B) *Do experts expect an alteration of user attitudes within the next ten*[10] *years?*, and (C) *What factors impede an alteration in user attitudes?* We contribute quantitative results of a multiple-year study on user attitudes towards smart glasses, which is to the best of our knowledge, the first one reported. We surveyed at three distinct points in time, supplementing a study of 2014 (c.f., Section 3.1) with surveys in 2015, and 2016. Our user study's results are complemented with an expert survey identifying weak spots and eliciting a prioritization of challenges for smart glasses adoption. We highlight notions regarding social acceptance, spectator attitudes and (un)obtrusiveness of the device. With our work we contribute to a better understanding of factors that impede or support smart glasses becoming habitual in real-life scenarios.

3.2.2 Multiple-year Case Study

We present a multiple-year observation of user attitudes towards smart glasses, complementing a previously published survey [KKM15]. Unlike in the preceding study, which focused on factors that influence user attitudes, the present study assesses changes in user attitudes over time and assess the user attitude at *three distinct points in time*, i.e., 04/2014, 04/2015, and 04/2016.

[10] c.f. Years to mainstream adoption for AR, Gartner Hype Cycle 2016, `https://www.gartner.com/en/newsroom/press-releases`, accessed 2019

Method

We conducted repeated measurements (2014, 2015, and 2016) following the study design and procedure described in Section 3.1. Participants were asked to rate a set of 56 scenarios (28 involving smart glasses, 28 smart phones) based on a semantic differential (c.f. Table 3.2). They indicated their subjective perception using a slider, comprising a range of -5 to +5 with a resolution of 1.0 (11-pt. Likert Scale). The questionnaire was filled out on a desktop computer in a quiet lab environment using a neutral survey platform. All participants were recruited via a regional recruitment platform, which, in contrast to online recruitment, allowed to rule out sampling errors due to changes in popularity of social networks or fluctuation of mailing list subscriptions. Thus sampling stability and a more reliable and valid between-subjects comparison can be achieved. Repeated participation of an individual participant in multiple runs was ruled out during recruitment. Monetary compensation according to the platform's convention (10 Euro/h) was disbursed after the study in a separate room and by personnel different from the experimenter. We analyzed the results based on the following hypotheses: H_1*: There was a significant alternation in user attitudes towards smart glasses between 2014 and 2016.* and H_0*: The user attitude towards smart glasses did not change significantly between 2014 and 2016.*, respectively.

Participant profile

Distributed over three distinct samples, 118 participants, aged between 18 and 58 (M=23, SD=4), 47% female, participated in our study (c.f., demography in Table 3.3). Professional backgrounds/study subjects were diverse with their distribution corresponding to the faculty-wise distribution of study subjects at the whole university (denoted in brackets), including law: 18% (19%), business administration and economics: 14% (16%), arts and humanities: 60% (57%), as well as informatics and mathematics 4% (7%). There were also 2% participants with other occupations and 3% with no subject indicated. This distribution indicates that the results of the survey can provide an accurate estimation of the user attitudes of the campus population (N=11957). However, as also discussed in the limitations section, the findings are not necessarily generalizable to other regions or populations.

Year	N	Female	Mean Age	Age Range	SD
2014	38	16 (42%)	23	18–38	4
2015	41	18 (44%)	22	20–31	3
2016	39	22 (56%)	23	20–56	6
Overall	118	56 (47%)	23	18–56	4

Table 3.3: Demography; Age profile and gender distribution.

Analysis and Results

With our study we replicated the study presented in Section 3.1, and re-conducted it twice over a period of two years. For analysis participants were grouped according to their year of participation. We evaluated the questionnaires reliability based on Cronbach's Alpha ($\alpha \in [0.95; 0.98]$[11]), which accounts for a high consistency within individual measurements [Loe01]. The answers to the semantic differential (11-pt., ordinal scale) were analyzed for each scenario and each pair of adjectives individually. Medians were determined and analyzed for significance (Kruskal-Wallis test, $df = 2$, adjusted for ties). With no statistically significant differences (all $p > .01$) found, the null hypothesis (H_0), stating that there is no significant alternation in user attitude between 2014 and 2016, has to be accepted.

Limitations

The case study's results confirm the (prevalently negative) user attitude towards smart glasses and their influencing factors found in our previous study (Section 3.1, [KKM15]). On top of this, the repeated study shows that there has been no significant change in user attitudes over the three years of investigation. While our findings are applicable to the student population in Passau, Lower Bavaria[12], Germany, our results might not be fully generalizable. Particularly, more progressive user groups (e.g., early adopters) or regions (e.g., Silicon Valley, metropolises) might already show first signs of an alteration in user attitudes, not captured by our study.

3.2.3 Expert Survey

Starting from those results we subsequently assess (based on expert opinions) whether those negative attitudes entail a lack of social acceptance and if benefits from smart glasses usage are capable of overwriting initial objections. With our expert survey we assess prognoses for the adoption of smart glasses, and identify open issues and disagreements.

We deployed our expert survey online via a neutral survey platform (i.e., not associated with a brand or manufacturer) to prevent sponsor bias. Its main part consisted of 2 two-tiered questions (6-pt. Likert scale with free text explanatory statement: Q1, Q3) and one asking the participants to rank improvement criteria by relevance (Q2).

Q1: Within the next 10 years: do you expect smart glasses to be worn by people as a matter of routine?

[11] Cronbach's α determined separately for each perspective (1st person, 2nd person) and device (smart phone, smart glasses).

[12] Details on the regions demographics available from `https://www.statistik.bayern.de/produkte/biz/index.html`, accessed 2019

Q2: What would have to be improved such that smart glasses can become a tool used by people in their everyday lives? Please provide us with a ranking. (Options based on [YYZ+16], c.f. Figure 3.8)

Q3: To what extent do you think that social acceptance will be relevant for the success of smart glasses?

In addition the demographic profile and professional background of the participants were assessed. The survey explicitly targeted participants that had prior experience with smart glasses (e.g., as developer, researcher or early adopter) or expert knowledge in the field of HCI/ICT. For recruitment we used snowball sampling in addition to purposive sampling via email and social networks based on pre-defined expert criteria (c.f. Table 3.4). Out of 90, 51 experts (36m, 15 f, 0d), aged 24 to 54 (M=35, SD=7) submitted completely filled out questionnaires. The majority of participants live and work in Europe (39, 76%) and the US/Canada (10, 20%), followed by Middle East/North Africa (1, 2%) and Asia (1, 2%). There was no compensation paid for participation.

Expert Profile	**Count**
UX/IxD Practitioner (min. 2 years experience*)	27 (53%)
Researcher (before PhD⋆)	11 (22%)
Researcher (Post-doc⋆⋆, Professor⋆⋆)	33 (65%)
Early Adopters (min. 1 month experience)	10 (20%)
Author, Journalist or Blogger†	7 (14%)
PR, Marketing, Sales (AR or HmDs)	3 (6%)
Developer (Smart glasses HW/SW)	17 (33%)
Other	2 (4%)

* Areas of expertise: User Experience Design, Interaction Design, User-Centered Design or similar.
⋆ Areas of expertise: smart glasses, head-worn displays, Augmented Reality, or similar.
⋆⋆ Areas of expertise: Human-Computer Interaction, Technology Adoption Research, Information Ethics, or similar.
† With at least one published article or blog entry covering wearable devices, smart glasses, smart contact lenses or other future, head-worn technologies.

Table 3.4: Predefined expert profiles, participants were presented with brief descriptions (including level of expertise) and asked for self-assessment, multiple selections were possible.

3.2.4 Results and Discussion

The participants' qualitative statements were analyzed independently by two coders with regard to re-occurring themes and arguments. Following the procedure of inductive category development [May14] results were categorized and summed up (occurrences denoted as n). We present themes and codes in Table 3.5. In the following we highlight the key findings and relate them to prior work.

Theme	Description	Code	n
Factors supporting smart glasses adoption	Reasons provided for expecting routinely smart glasses usage.	hands-free interaction	5
		situated information access	7
		natural interaction	4
Factors impeding smart glasses adoption	Reasons provided for not expecting routinely smart glasses usage.	utility	12
		ergonomic issues	13
		pricing	4
		usability	3
		social image	18
		privacy	7
		ethical issues	9
Specialized Application Areas	Restrictions named for expected routinely smart glasses usage in terms of application areas or use cases.	general	18
		work	15
		sports	4
Casual Usage	Likelihood of casual, every-day usage of smart glasses by consumers/non-professionals.	likely	6
		unlikely	7
External Influence on Social Acceptance	Factors influencing the social acceptability of smart glasses that are not device related or include aspects independent from device design.	matter of time	5
		matter of exposure	2
		result from weighing benefits	4
		comes naturally	2
Design Requirements for Social Acceptance	Design or device related factors influencing the social acceptability of smart glasses	appealing design	17
		coolness factor	4
		unobtrusiveness	7

Table 3.5: We employed inductive category development [May14] to code responses to open-ended explanatory statements of Q1 and Q3. List of themes and codes that emerged during category development; the last column shows the number of participants (n). N=51. Codes with n<2 omitted for clarity.

Prognoses

The majority of participants estimate smart glasses to be worn as a matter of routine within the next 10 years (Q1, Median=3, SD=1.3); also shown in Figure 3.7. While participants value the advantage of hands-free interaction (n=5), situated information access (n=7), as well as natural interaction (n=4) they also name both technological and societal issues that would have to be solved before wide adoption becomes possible. Particularly, opinions diverge regarding the pervasiveness of adoption and prerequisites that would have to be met. Participants expect smart glasses to be successful in specialized application areas (n=18), such as the work place (n=15) or sports (n=4). Opinions were divided whether adoption by consumers for casual usage is likely (n=6) or unlikely (n=7).

Prerequisites for Adoption

Subsequently, we highlight the most frequently named factors that impede the adoption of smart glasses. Overall, a lack of suitable use cases and useful applications (*utility*, n=12) was discerned. Participants agreed that overcoming the current lack of utility is crucial for adoption: *"So given we come up with suited application scenarios, smart glasses will become ubiquitous"* (P71). Furthermore, participants criticized a lack of wearing comfort and named *ergonomic issues* (n=13) as hindrance for adoption. P40 states *"form factors are too cumbersome and do not outweigh the provided utility"*. This critique is also backed by previous results by Genaro Motti et al. [GC14a] who note a lack of "wearablity" of current devices. Moreover, *pricing* will have to decrease (n=4) for smart glasses to become more affordable. In addition, *usability* (n=3) has been raised as issue: *"They do not yet present a superior means of communicating information to a user, because the interface is not nimble to manipulate"* (P24). Perceived awkwardness and social shaming (*social image*, n=18), as well as *privacy* (n=7), and *ethical issues* (n=9) have been also noted to impede the adoption of smart glasses.

Need for Improvements

Q2 asked the participants to rank given areas of improvements according to their relevance for the adoption of smart glasses. Figure 3.8 illustrates the overall ranking (middle, dark blue, N=51) along with rankings by sub-samples that rated social acceptability either more important (N=27), i.e. below the median or less important (N=24), i.e. above the median. Rankings were determined based on aggregated scores (Borda count). Differences between sub-groups are significant ($\chi^2(48, N{=}421) = 148.17$, $p < .001$, $V = 0.45$). Usefulness, functionality, and usability, along with compatibility with daily routines have been concordantly identified as most important areas for improvement, also reflected in the qualitative accounts. Those results are further backed by Shackel's acceptability equation [Sha09], which balances utility, usability, likability against cost.

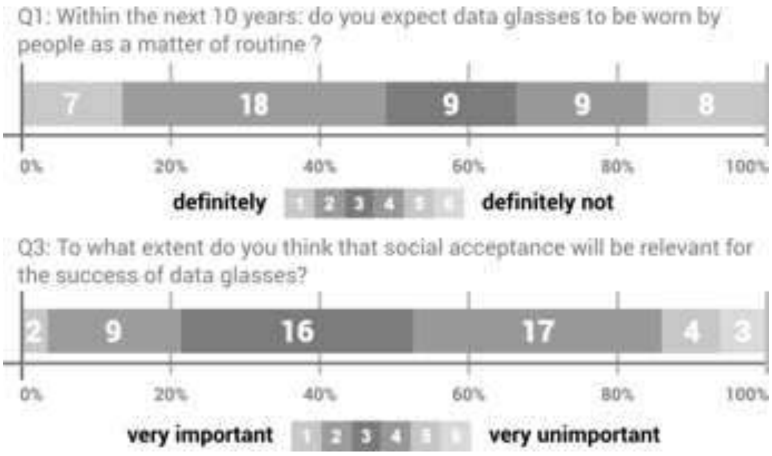


Figure 3.7: Answers to Q1 (top, Mdn=3, SD=1.3) and Q3 (bottom, Mdn=3, SD=1.2), measured on 6-pt. Likert Scales.

How Relevant is Social Acceptance?

Along with the improvement of the *Social Image* that was subordinated in Q2 (c.f. Figure 3.8), only a small majority indicates social acceptance to be slightly important (3) or important (2, Mdn=3, SD=1.2, c.f. Figure 3.7) for the adoption of smart glasses. Interestingly, participants were in disagreement whether social acceptance is a matter of time (n=5) and exposure (n=2) or if it results from weighing benefits (n=4). Participants also stated that social acceptance comes naturally (n=2), and one participant challenged whether social acceptance can be supported by design: "After all, how can you design for social acceptability?" (P12); Which we take up as a research question for this thesis.

What Role does the Spectator Play?

Our qualitative analysis revealed that the participating experts were discordant about the spectator's role in user acceptance. While some participants highlighted bystander perceptions to be relevant (n=7) others explicitly doubt (n=2) that spectator acceptance influences smart glasses adoption. While related work in the field of mobile computing has shown, that spectator acceptance influences preferred interaction styles [RB09; BMC+09], there is few work on its influence on the adoption of mobile devices that are present in the media long before their availability to the consumer.

Level of (Un)obtrusiveness?

While appealing design (n=17), along with the *"Coolness Factor"* (n=4) was frequently named as prerequisite for adoption (Q1), multiple participants consider the resemblance to prescription glasses as crucial. They expect miniaturization

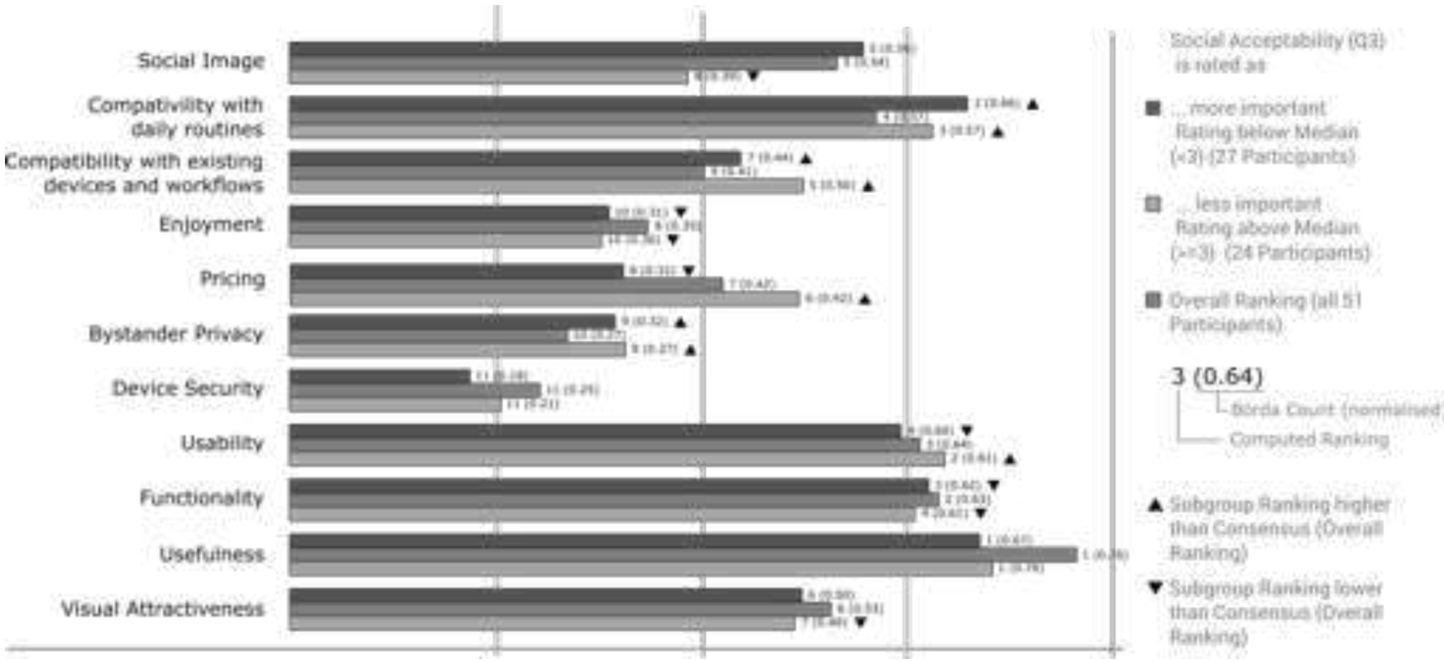


Figure 3.8: Ranking of required improvements for long-term adoption based on aggregated scores (normalized Borda count, in brackets), changes in ranks indicated by arrows.

and unobtrusiveness (n=7) to result in a higher social acceptability. P71 states *"Once we hit the point where smart glasses are looking just like normal glasses [...] adoption will increase drastically"*. However, increasing the unobtrusiveness of smart glasses might intensify a different set of problems. While the user becomes less prone to objections and social shaming, issues of (bystander) privacy (n=7) arise: it is unclear whether a device with camera is present and/or recording. The question whether interactions with a mobile device shall be unobtrusive [AGW+15; DHR15] or candidly communicated [EGA+15] has been adressed in earlier research (e.g., by Reeves at al. [RBO+05]) and also raised by P26: *"There is also the issue that the manipulations are highly visible, but the effects are not [...]"*. Finding the "right" level of (un)obtrusiveness will be a challenge for future research; requiring to balance a trade-off between being unsuspicious and straightforward: they require *"[s]ubtle design that allows them to stand out, but not so obviously different"* (P76).

3.2.5 Summary

In this section we investigated factors impeding and supporting smart glasses adoption. Based on a 2014 to 2016 case study, we demonstrated that user attitudes have been stable and prevalently negative over the last three years. However, our survey among 51 experts shows that an alteration in user attitudes as well as an adoption of smart glasses is expected until 2026. While social acceptability is considered relevant for the time being, experts expect it to be overwritten by more fundamental factors on the long run. They identify (1) Usefulness, (2) Functionality and (3) Usability as most crucial to long-term adoption. Moreover, unobtrusive design is named as a key strategy for improving the social image.

Our present work demonstrates that smart glasses, though already launched to public and widely discussed, still pose manifold challenges to (HCI) research and will not be accepted without efforts. In order to create utile applications (Usefulness) we require more user research, involving in-depth requirements analysis, and deep understanding of specialized (professional) use cases. Novel or improved hardware capabilities, and powerful tracking methods will be prerequisite to providing the needed services and functions (Functionality). Current usability issues (Usability) will be a challenge not only to usability research but particularly to those looking into novel, advanced interaction methods and visualization techniques. Finally, design disciplines, e.g., interaction design, will be challenged to determine the "right" level of unobtrusiveness for smart glasses and interactions.

3.3 Summary and Conclusion

In this chapter we took a close look at factors that influence the social acceptability of smart glasses. Results from our focus group and lab survey (Section 3.1) suggest conflicting user and bystander needs as major cause for their lack of social acceptability: **freedom of choice vs. privacy protection is controversial.** Moreover, we identified the integrated camera, which is supposedly always on, as problematic in social context: **recording matters**. This effect is intensified, as smart glasses, being worn instead of hand-held do not provide sufficient indication of the camera status, i.e., whether the camera is turned on or off. We furthermore provided experimental confirmation that **knowledge about usage intentions affects social acceptability**. These findings are central to the design activities in the remainder of this thesis and had been confirmed by multiple researchers [ASV^{+}18; AKP^{+}18; HVC^{+}15; BBV^{+}19] after the first publication of our results [KKM15]. We further believe that these findings generalize to other wearables that have a (front-facing) camera irremoveably integrated. We extend this line of thought in the following chapters by extending the focus from smart glasses to body-worn camera devices in general.

3.3.1 Limitations

The work presented in this chapter made – to a large portion – use of scenarios. Scenarios and story-telling methods have become one of the most established methods to explore social acceptability in HCI (c.f., Section 2.2), and have various advantages: they are highly flexible as they allow to test envisioned, not yet implemented, use cases; They are well controllable, which allows to mitigate bias, and they allow to isolate individual factors to compare their effects. However, they also induce certain limitations. The most important weakness of scenarios is that they require participants to imagine the use of an interface in a hypothetical situation: they include an "imaginary" component. In consequence, they rely on the participant's ability to imagine themselves in the shown situation and may be challenged in terms of external and ecological validity: the participant has no first-hand experience and might err in terms of how they might feel or react. As a result, scenario-based results cannot provide absolute measures; they cannot tell whether an interface would be accepted in practice or not (i.e., if it would reach a certain "threshold" of acceptability). As a result, the scenario-based studies presented in this chapter can only provide explanations to the real-world observation that smart glasses are not adopted; they do not provide an "acceptability measure" for smart glasses. Nevertheless, they allowed to isolate the variables perspective and usage intention, which allows for direct comparison and high relative validity.

In addition, the way how the scenario itself is presented has a potential impact on how it is perceived. We intentionally decided for abstract sketched scenarios, to reduce gender or cultural bias. Our efforts to provide an as neutral as possible scenario that is non-restrictive and open to imagination are in line with prior work. For instance, Rico et al. argue: *" […] videos used in this survey intentionally portrayed a plain scene without a defined context so that the setting would not distract viewers from evaluating the gesture"* [RB09]. On the other hand, showing a realistic usage scenario, is naturally more illustrative and can facilitate the participants imagining the depicted situation. Then again, imagining the same interaction in an environment other than the depicted one could be hampered. Moreover, complex, realistic videos also introduce practical difficulties in terms of controlling confounding variables: when shooting variations of the same video multiple times (e.g., to introduce independent variables to the experiment), all variations in the video (or photograph, c.f., [SRR+18]) other than the manipulated variables, e.g., the actors expressions, could – potentially – induce bias. Stimuli limited to the essential, such as sketches, are thus easier to extend, e.g., by adding further interaction styles after one study iteration, and can be easily re-used. Hence, the scenarios developed for Chapter 3.1 might be re-evaluated in different cultural contexts, or at a later point in time – similar to the multiple-year case study presented in Section 3.2.

3.3.2 Implications

Is social acceptability something to be addressed by HCI research? When we surveyed prognoses and factors for smart glasses adoption among experts (Section 3.2), we identified usefulness, functionality and usability as crucial factors for long-term adoption – a finding that is consistent with Shackel [Sha09]. Interestingly, the participants were divided in terms of the relevance of social acceptability, and some even questioned whether social acceptability would lie within the scope of HCI. However, the "negative social image" of smart glasses was most frequently mentioned as current inhibiting factor for adoption. From our perspective, it is thinkable that usefulness, functionality, and usability will – as suggested by some participants – override social acceptability on the long run as a result of weighing benefits, time and exposure. Nevertheless, we are convinced that the field of HCI should research strategies to design for social acceptability, as exposure requires a sufficiently large base of early adopters. This is important, because many innovations find their most utile applications in specialized areas with only a small number of users. For instance, an application might bring significant improvements for assistive use cases, but provide only "nice to have" or "just for fun" features for mainstream users (c.f., the recent NaviLens project by Transports Metropolitans de Barcelona [Swa19]). In consequence the application would only be considered highly useful by a small number of persons, while the majority might doubt utility. Nonetheless the minority user group (in the above mentioned example visually impaired users) should be able to use the technology comfortably in public as soon as it becomes available, and without waiting for sufficiently utile mainstream applications. Hence, we believe that it is the designer's responsibility to create interfaces, for both small and large user groups, socially acceptable right away, without counting on time or exposure. This further motivates the design activities and methodical reflections presented in the remainder of this thesis.

4 Ideating Privacy Mediation

In the context of body-worn cameras, visual privacy is a major issue, as "recording matters" (Section 3.1). We consider it a breach of privacy, when information about a person's "private life, habits, acts and relations" becomes available to others [Gla79]. Nevertheless, what kind of situations are perceived as (privacy) sensitive is highly subjective and may vary between individuals [PSC+17]. Thus, an essential aspect of privacy with "always-on" cameras is that bystanders have the right and ability to *subjectively* choose when, where, and by whom they are recorded [GAJ+14]. In practice however, most body-worn cameras do not provide any procedure to do so, except for (verbally) addressing the device user. Following Denning et al. [DDK14] we refer to technical means that support this procedure as *privacy-mediating technologies*, and to the procedure itself, which can but does not have to be technology-supported, as *privacy mediation*.

In this chapter, we look into *privacy mediation* from three angles. We start by presenting (1) a tool for participatory design, a dedicated card deck, that makes privacy-mediating technologies accessible to stakeholders with varying technical background (Section 4.1). Based on design-in-use studies we reflect on the cards' usage, discuss privacy mediating procedures suggested by the participants, and identify two design challenges; namely, the provision of unadorned preparation-free bystander controls, and the design of suitable privacy indicators. We address these two challenges in the two subsequent sections. More precisely, we explore (2) gestures as consent mechanisms to Opt-in or Opt-out of a recording (Section 4.2) and (3) design options for camera status indicators that go beyond the established choice of point light displays, i.e., LEDs, (Section 4.3).

From a methodical perspective, this chapter exemplifies how aspects of an interface (here: privacy threats) that cause social acceptability issues can be approached with a participatory mindset (c.f., Section 2.3.3). It focuses on idea and concept generation, and represents HCD's *Ideate & Design* phase. We show one example of how participants with varying technical background can become involved in the design of socially acceptable (technical) procedures. While the presented work focuses on privacy, we believe that the provision of a mutual knowledge base (here: the Privacy Mediation Cards) can aid with the (re-)design of controversial technologies, particularly where conflicts between users and bystanders or other stakeholders arise. In addition, we exemplify how participatory design approaches (e.g., elic-

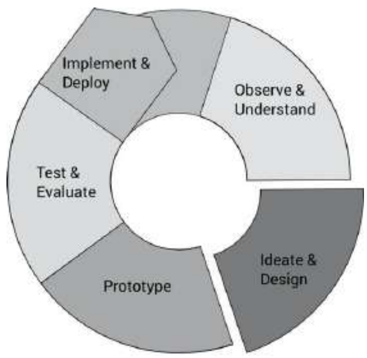


Figure 4.1: Human-centered Design Process. This chapter implements the *Ideate & Design* phase.

itation studies, Section 4.2) can be combined with methods that are traditionally employed to investigate social acceptability in HCI (e.g., online surveys, Section 4.2). We furthermore elaborate how design activities with UX/HCI experts (Section 4.3) can utilize design thinking and include aspects from critical and speculative design. We found this approach useful and suitable in situations where more established methods (c.f., Section 2.2) and participatory design fail to breach established thinking patterns, and lack the necessary innovative strength. We hope the presented method will inspire new approaches for re-considering established, but not socially acceptable, designs and form factors.

4.1 Facilitating Participatory Design: Privacy Mediation Cards

While there is a range of technical opportunities that enable privacy mediation between users of body-worn cameras and bystanders, these options are often not well communicated to stakeholders that are no experts in privacy enhancing technologies. In this section, we present the Privacy Mediation Cards, a dedicated card deck that provides a structured overview of conceptual and state-of-the-art procedures and technologies for privacy mediation. The card deck targets non-experts with varying technical background, including experts from other relevant areas, such as social and political sciences, or law, developers and UX designers, as well as citizens. We identified the need for an intelligible overview of knowledge based on observations made during a workshop on “opportunities and risks of smart cams in public spaces” held by the University of Oldenburg[1] and the Data Protection Advisory Board of the Deutsche Bahn in June 2016 [Tae17]. The workshop engaged societal stakeholders, including members of the parliament (German Bundestag), federal police, and the Federal Association for Information Technology (BITKOM), as well as experts from political and social sciences, and media representatives. During the workshop, social and legal issues with “ubiquitous smart cameras” were discussed in-depth, and gaps, where legal regulations and social norms fail, were identified. In contrast, technical opportunities, including privacy enhancing and mediating technologies, as well as their synergy with legal and organizational frameworks (e.g., via certification) were brushed, but only sparsely taken up during the discussions. This anecdotal evidence, and similar observations from focus group discussions with citizens [ECK17] (part of the same project), imply that a lack of a (mutual) base of technological knowledge may be one of the causes that hinders the discussion of solutions based on state-of-the art technological approaches – the gap addressed by the Privacy Mediation Cards.

[1] As part of the BMBF project ChaRiSma, `http://www.charisma-projekt.de/`, accessed 2019

Figure 4.2: What technologies are available to design socially acceptable and privacy-preserving body-worn cameras? The Privacy Mediation Cards provide overview of conceptual and state-of-the-art technologies, and make this knowledge accessible to non-experts.

4.1.1 Contributions and Related Work

Recent commercialization attempts of head-mounted non-immersive displays, so-called smart glasses or data glasses, evoked a societal discourse on how these devices might or might not be used in public spaces. In particular, they were deemed disrespectful, and were subject to social acceptability issues and privacy concerns caused by the integrated camera [KKM15]. In contrast to stationary, often publicly owned CCTV cameras, such personal, body-worn camera devices intensify bystanders' privacy concerns (c.f., Wolf et al. [WSB+14]). While the public discourse often juxtaposes complete ban and unrestricted usage, we argue that there is a range of options between those two extremes. Nevertheless, engineering socially acceptable, privacy-preserving smart glasses requires a careful selection from a range of available privacy-mediating procedures. Based on in-situ interviews with bystanders of smart glasses, Denning et al. [DDK14] explored design directions, and provide an systematization of privacy-mediating technologies and procedures (see Figure 4.3). The state-of-the-art of privacy-enhancing technologies (PETs) has been systematically reviewed by Krombholz et al. [KDS+15], and Perez et al. [PZG17] proposed a taxonomy of methods for bystanders' privacy protection. However, the intended audiences of those systematizations are researchers and professionals, i.e., experts. In consequence, knowledge about privacy-mediating procedures is not yet readily available for non-experts (e.g., citizens), which hinders non-binary, and factual public discussion, as well as participatory and interdisciplinary design. In this work, we introduce a tool, an illustrated card deck (Figure 4.2), that makes knowledge about privacy-mediating procedures accessible

Push		Pull
Proactive		Reactive
Opt-in		Opt-out
Recording-time		Sharing-time
Compliance-dependent		Compliance-independent
Enforced		Suggested
Place-based	Proximity-based	Identity-based
User-based	Bystander-based	Third-party
Technical	Physical	Social

Figure 4.3: Design axes for privacy-mediating technologies, as proposed by Denning et al. [DDK14].

for stakeholders with varying technical background and serves as a facilitator for participatory design sessions. The Privacy Mediation Cards synthesize privacy mediating technologies and procedures for smart camera devices into intelligible explanations, provide structure and categorization, and illustrative visualizations. The card deck's categories, explanatory texts, and visualizations were developed and refined through an iterative process, incorporating results from design-in-use studies, informal peer feedback (gathered at scientific conferences), re-design sessions and reviews with experts. It aims to make informed discussions possible, and to allow for design processes that engage a wide range of relevant stakeholders, such as citizens, social and political scientists, or jurists, but also developers and UX designers. To this aim, we report first observational results from design-in-use studies, where we tested the applicability of the card deck in participatory design sessions.

4.1.2 Privacy Mediation Cards

Here, we elaborate on the card deck's design and development process, and go into detail on its structure and contents.

Design & Development Process

Card decks have been successfully employed by prior work to outline specific domains (e.g., in [WRB17]), and to synthesize (design) knowledge for collaborative design. However, work describing the design process in a generalized, replicable fashion is sparse. Müller et al. [MGV$^+$14] describe a five-step process of evolving a framework, the exertion framework, into cards – the Exertion Cards. The process they describe consists of establish target boundaries, scrutinize framework, reduce

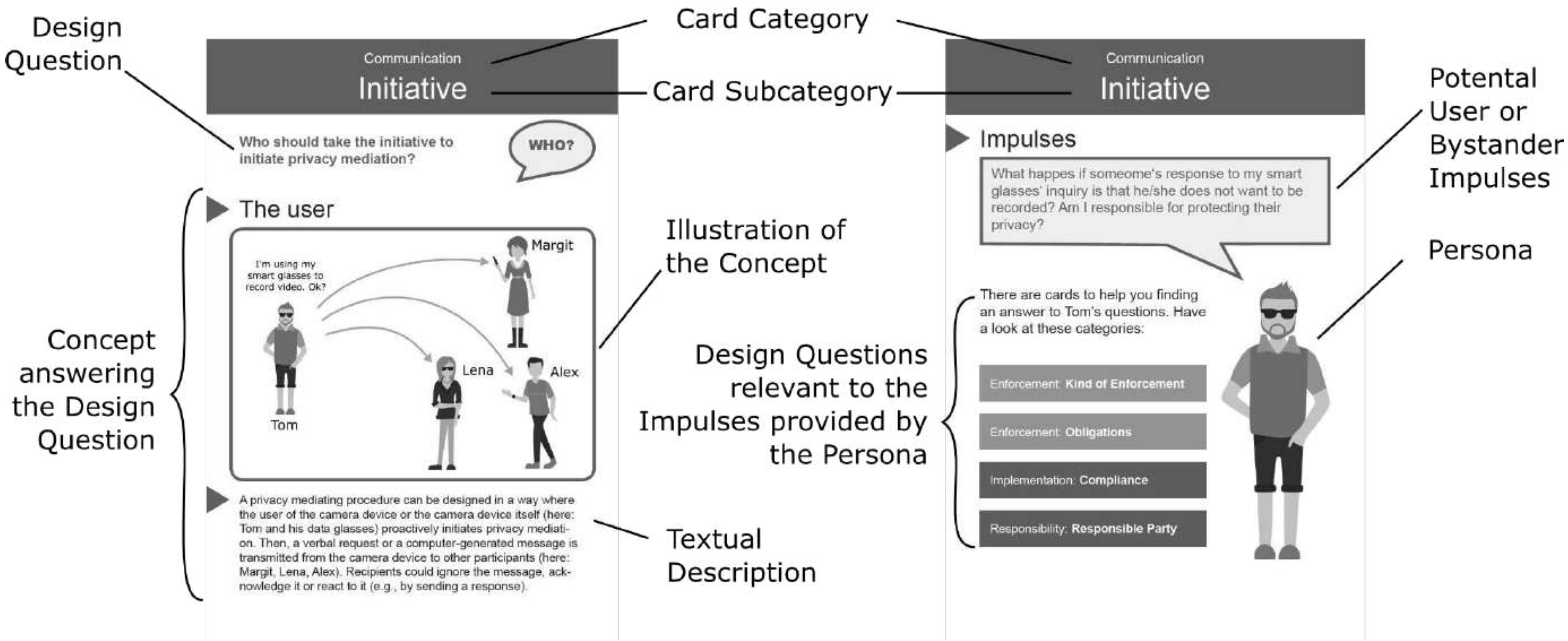


Figure 4.4: Card layout; Concept on the front side (left), impulses on the back (right). Impulses refer up to 4 other design questions (subcategories).

items, visualize, and incorporate feedback. We based the design process of our Privacy Mediation Cards on this process as outlined below (steps 1-6).

> 1. **Define Topics & Synthesize Themes**
> Structured analysis of literature and state-the-art of privacy mediation. Inclusion of both conceptual/prototypical approaches, and off-the shelf technologies.
> 2. **Target Boundaries**
> Overview character; Target range of 30-40 cards.
> 3. **Scrutinize Range of Themes**
> Establishing structure and hierarchy; Definition of categories, and subcategories. Inclusion and exclusion of themes/concepts.
> 4. **Reduce, Split or Merge Items**
> Iterative refinement of concepts, resulting in 34 cards.
> 5. **Visualize**
> Creation of one illustration per card, visualizing the card's main concept.
> 6. **Incorporate Feedback**
> Iterative refinement (steps 3-5) based on (expert) feedback, and design-in-use studies.

In contrast to the Exertion Cards, the Privacy Mediation Cards did not start out from an existing framework, but were designed based on results of a literature analysis (Step 1. Define Topics & Synthesize Themes). Topics and themes were chosen through initial collection of available options based on a in-depth analysis of literature and state-of-the art (c.f., Table 4.1). In addition, we reviewed existing systematizations [DDK14; KDS+15; PZG17]. Results were grouped in affinity diagrams, and included both, conceptual and prototypical approaches, as well as available off-the-shelf technologies. The initial grouping and structure was mostly based on Denning et al. [DDK14], Krombholz et al. [KDS+15], and Perez et al. [PZG17], but largely evolved in the subsequent steps of card deck development (Steps 1-4). For the Privacy Mediation Cards, we decided on illustrations that visualized the card's concepts and provided an easy entry point for discussion (Step 5). Arrows, icons and symbolic representations illustrate digital, or otherwise invisible or abstract properties. At the same time, we took care to keep the visualizations as general as possible, to keep them open for idea generation, and to not imply any specific brands, protocols, or standards (e.g., encryption).

Subcategory	Concept	Scientific Work
Initiative	The user The bystander(s)	[DDK14], [KDS+15]
Channel	Face-to-Face Wireless-Signal-based Trusted 3rd-Party Service Visual-Signal-based	[ASD+16], [MSC+09], [KDS+17], [CNI+08], [HSS13], [GAJ+14] [BQQ+11], [SZH18], [BSL+14], [NG03], [SZH17]
Audience	To the user To bystanders To third parties	[SBD+15]
Information Content	Binary (ON - OFF) Content-based Intention-based	[EKC15], [SBD+15], [Man14], [KWB18]
Default Behavior	Obfuscation No obfuscation	[DDK14], [KAC+18]
Timing	Before the recording After the recording	[DDK14]
Inclusion & Exclusion	Physical artifact required Smart phone required Accessibility	[KDS+15], [AKP+18]
Kind of Enforcement	Technically Physically Social norms	[BKD+08], [GTK+12], [CPT04]
Obligations	Compulsory Suggested	[YXH+17], [ECK17]
Compliance	Compliance-dependent Compliance-independent	[ANG+14], [YGE13], [DKW+15]
Parameters	Location-based Identity-based Proximity-based Time-based	[PYK+14], [TKC+14], [MSC+09], [RCS+14], [KTC+14], [GAJ+14]
Responsible Party*	The device user Everyone individually The manufacturer Legislation	[Mon15], [ECK17], [SLZ18]

*) added after iteration.

Table 4.1: Overview of individual cards (middle) along with subcategories (left) and exemplary scientific work (right) for each subcategory. Main categories are indicated as colored bars (left).

	Category	# cards
	Communication	6
	Visibility	6
	Participation	7
	Enforcement	7
	Implementation	4
	Responsibility	4
		34

Table 4.2: The deck's 34 cards are organized in 6 color-coded main categories.

To iteratively refine and evolve the card deck, we conducted a re-design session with 5 team members of our institute. During this 3h re-design session we discussed the overall structure, and contents of the card deck's initial version with an aim for a (critical) redesign. We focused on the utilization of the cards' back and front, their size and format, missing/unnecessary topics, level of details and terminology of headlines (Step 6). After the workshop the cards were iterated based on the workshop's results (Steps 3-5). Subsequently, the iterated card deck was again reviewed by the same team members with regard to the made changes. This procedure aimed to ensure that ideas and feedback gathered during the re-design session where correctly integrated. Additionally, the reviewing team members also looked at terminology in the explanatory texts, including wording (e.g., understandability, and correctness of the provided information), and consistency. We furthermore gathered informal peer feedback at conferences, and included feedback that we had received from the design-in-use studies which we report on subsequently in Section 4.1.3.

Card Deck

The final version of the Privacy Mediation Cards consists of 34 illustrated cards that provide a systematic overview of both, available and conceptualized technologies, procedures and concepts that could enable privacy-preserving public usage of body-worn cameras. The card deck comprises six categories: communication, visibility, participation, enforcement, implementation, and responsibility (c.f., Table 4.2) which are divided into subcategories (2-4 cards each) that each pose a design question. Each card suggests one concept or technology answering to its subcategories design question (front), and providing impulses for further exploration (back), as depicted in Figure 4.4. The impulse side (back) is augmented with a persona to facilitate discussions and enable the participants to empathize with different stakeholders. The card deck abstracts from a range of scientific works, as exemplified in Table 4.1, presenting them in a simplified, visual manner. The full (printed) card deck is available as print-on-demand [Koe19], and in excerpts at `https://privacymediationcards.uol.de/`.

4.1.3 Design-in-Use Studies

Design-in-use studies yield first impressions of how design tools, such as card decks, might be used in practice [BA11]. Subsequently, we jointly present results from two design-in-use studies and discuss how the Privacy Mediation Cards were used and appropriated.

	Intro	Group Work	Discussion
WS1	60 Min	60 Min	10 Min/Group
WS2	45 Min	3x30 Min	10 Min/Group

Table 4.3: Procedure and timing of workshop 1 (WS1) and workshop 2 (WS2).

We conducted two similar participatory design workshops where the Privacy Mediation Cards were used as a tool for developing ideas for privacy-mediating smart cameras that would be – according to the participants – socially acceptable. One workshop (WS1) was held at the University of Oldenburg as part of a student-organized conference on social, economic, and environmental sustainability (Nachdenkstatt, `https://nachdenkstatt.de/`). Participation was self-selective, as participants opted for WS1 by enrolling for the conference's digitalization track. Participants in WS1 were provided with sweets, but did not receive monetary compensation. For the other workshop (WS2), which was held at OFFIS, participants were students recruited from the local campus population using quota-sampling (aiming for 1f/1m per department) to represent a variety of study subjects and professional backgrounds. Participants in WS2 were served beverages and snacks and received a gift voucher (EUR 20) in appreciation of their time and efforts. Feedback from the workshops was continuously feed back into improving the card deck. In both workshops the participants were asked to *use the Privacy Mediation Cards to develop ideas for privacy-mediating "smart" body-worn cameras devices that they would consider socially acceptable*. Due to successive improvement and iteration, the deck provided to participants in WS2 contained the Responsibility/Responsible Category, not (yet) present in WS1. After providing informed consent, participants were introduced to the topic of smart wearable cameras, and how they might cause potential privacy concerns, and issues with social acceptability (Intro). Participants were also provided with a questionnaire on demography and technology affinity that was collected at the end and that they could fill out at any time during the workshop. Subsequently, they were asked to work in groups of three to come up with one concept of a privacy-mediating body-worn camera (Group Work). Each group was provided with one set of cards, and asked to document their solution on a poster. Finally, each group presented their solution orally in plenum (Discussion). Timing differed between WS1 and WS2, as documented in Table 4.3. Final presentations were video recorded, and transcribed for later analysis.

4.1.4 Results and Discussion

In total, 26 participants attended the two workshops (see Table 4.4 for demography). Participants in WS1 were mostly enrolled in social or political sciences at various German universities, whereas the participants in WS2 were distributed over the local universities departments, including (1) education and social sciences, (2) humanities, (3) computer science and law, (4) languages and cultural studies, (5) medicine and health sciences. In the end of the Group Work phase all nine groups had successfully come up with ideas for privacy-sensitive, socially acceptable body-worn cameras. Due to time limits, the solutions' level of detail varied between WS1 and WS2. In both workshops, the participants adopted the cards' phrasing and terminology, which was noted as advantageous for creating common ground. Overall, the Privacy Mediation Cards were received positively.

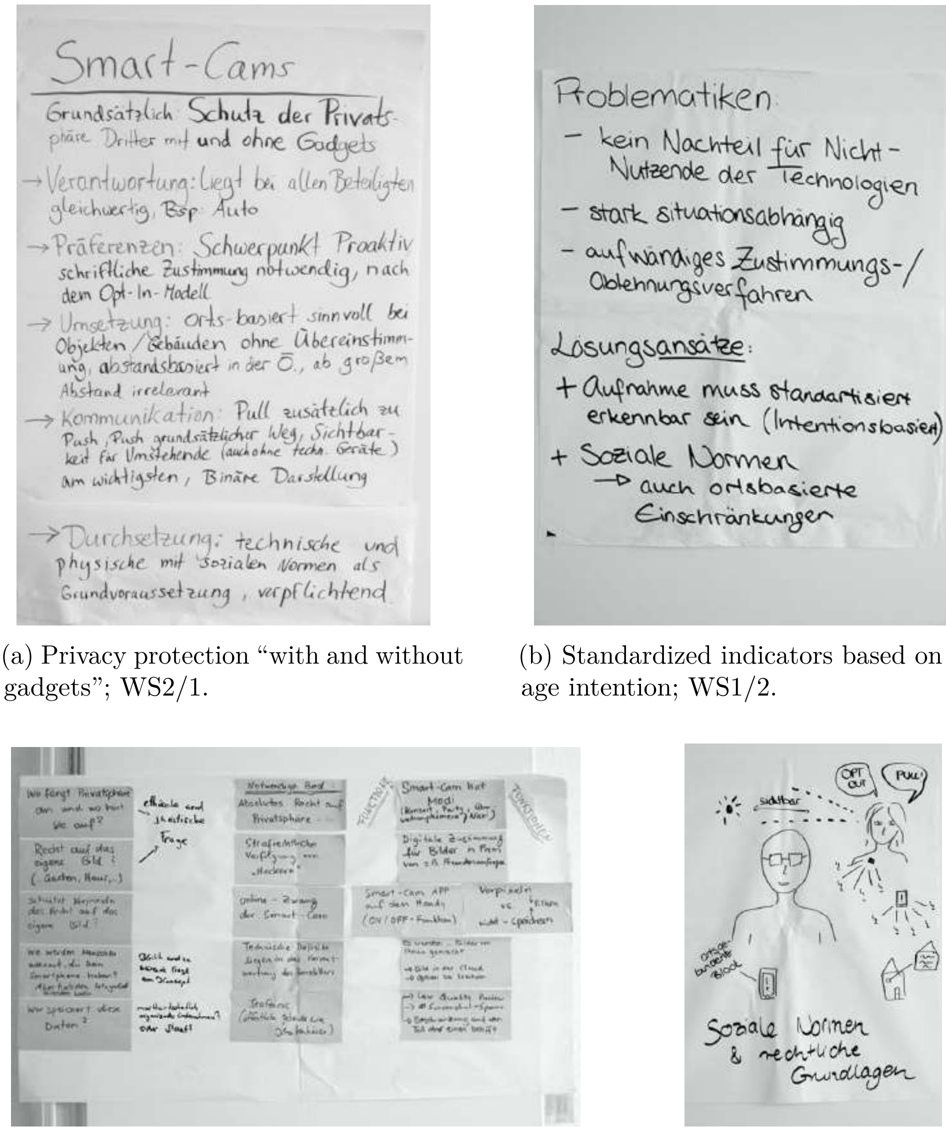
	# participants	age range
WS1	15 (4m, 11f, 0d)	18-28 (M=23, SD=3)
WS2	11 (7m, 4f, 0d)	21-30 (M=26, SD=3)
	26 (11m, 15f, 0d)	18-30 (M=24, SD=4)

Table 4.4: Participants' demography for WS1 and WS2. Recruitment for WS1 was self-selective as it was held as part of a student-organized conference. Participants for WS2 were recruited via quota-sampling on campus.

Privacy and Functionality

All participants recognized the presence of camera-equipped devices, such as smart glasses, in public spaces as conflictual. Participants noted re-occuringly the difficulty of balancing the protection of privacy (with the help of technical measures) while at the same time keeping the restriction of the functionality, and the impact on the user's freedom to a minimum (WS1/2, WS1/4, WS1/5)[2]. Participants highlighted the importance of social norms and legal fundamentals (c.f., Figure 4.5c and 4.5d), but also noted that those might not suffice: *"I think social norms are incredibly difficult, e.g., once it gets international"* (WS1/4). Only one group (WS1/3) favored a complete ban on public use of smart glasses and other wearable camera devices. In particular, participants stressed practicality and comfort as requirements. However, they also noted, that privacy protection and functionality are not necessarily antithetical: *"[...] when I use the [visual, AR] navigation function of my smart glasses to find my way through the city center, it's OK if all people are blurred because it is not the face of a stranger that matters to find from A to B, but whether [the tracking] sets the arrows on the street correctly"* (WS2/1).

[2] We denote Workshop 1, Group 5 as WS1/5.



(a) Privacy protection "with and without gadgets"; WS2/1.

(b) Standardized indicators based on usage intention; WS1/2.

(c) Combining legal frameworks and (mandatory) device functions; WS2/4

(d) Variants of bystander control; WS1/4.

Figure 4.5: The group work's results were presented orally with the aid of a poster and discussed in plenum. Exemplary solutions from WS2 (left) and WS1 (right).

Bystander Initiative and Blocking Devices

Seven of nine groups argued that a process of privacy mediation has to be initiated by the user, and that bystanders should not have to take action to protect their privacy. They favored procedures that ensure privacy by default (c.f., Figure 4.3, "Opt-in"). In contrast to findings from interviews conducted by Denning et al. [DDK14], blocking devices or "Opt-out gadgets" (c.f., Figure 4.5d) were seen critical: *"There must be options without technology to clearly communicate [whether] one wants to be recorded or not"* (WS1/2). However, participants also noted the possibility that bystanders might be indifferent, and not care about the presence of a (head-mounted) camera device. The groups particularly stressed that they wanted to provide an option that would not require bystanders to prepare in any way, e.g., by installing an app, acquiring an gadget, or registering. Specifically, the latter and other solutions that would require establishing a profile with a third party, such as a manufacturer or service provider, were regarded less desirable then unadorned and preparation-free variants (e.g., gestural commands, see Section 4.2): *"In the end you pay for this service with a lot of data about yourself"* (WS2/1).

Privacy Indicators – Yes, but how?

All groups stressed *"that the recording device must be recognizable"* (WS2/3), but noted that they were unsure about the design of suitable status indicators. For instance, Group WS1/2 suggested: *"[It is] visible to bystanders what you are doing right now – with different colors. For example: red: video, green: Augmented Reality"*. In contrast, Group WS2/4 noted: *"We reduce the information of this red dot [LED] to 'Something is happening' [..] if we would show that [the device] is doing motion tracking with it's this camera, then you look at it and ask yourself what was that symbol again [...] and when I look from 20 meters, then I can't recognize it at all"*. Overall, three groups included binary (ON/OFF) indicators in their suggestions, and two groups decided to utilize the usage intention in the indicators; the other groups were uncodeable. The choice of binary indicators was partially motivated, by the difficulty to design other types of indicators in an understandable way (WS1 and WS2), and without impairing user privacy (WS1). The design of status indicators is indeed challenging, specifically as status LEDs are not always optimal [PLE+15]. Developing a suitable iconography for this purpose has been covered by Egelman et al. [EKC15]. They note that icons *"should be designed to convey what information will be used by applications, not how it will be collected,* which is also consistent with our findings: "It is place and intention of use that matter" (WS1/4). However, privacy indicators do not necessarily have to be point lights (LEDs) or based on icons. We go into detail on possible alternatives in [KWB18], and in Section 4.3.

Timing and Default Behavior

Denning et al. [DDK14] distinguish between "Recording-time" and "Sharing-time". Although not explicitly included in the card deck, aspects of timing and sharing were re-occuringly discussed in both workshops. All groups stressed proactive approaches that communicate and enforce privacy preferences before or at recording-time: *"With regard to preferences, we said that the emphasis should be on proactively agreeing in advance or obtaining prior consent [...] before the damage has been done [...] because otherwise if [the picture] is online, and you object twelve hours later, it was already twelve hours on the Internet"* (WS2/4). However, the question of what default behavior, i.e., obfuscation or no obfuscation, would be desirable (discussed as Opt-in/Opt-out by Denning et al [DDK14]) was discussed controversially, specifically with regard to practicality. While the majority of participating groups chose a Opt-in principle, they also vocalized doubts in terms of how they could be implemented (WS1/1, WS1/3, WS2/1, WS2/3, WS2/4). Only wo groups suggested Opt-out. Both motivated their choice through practicality and by referring to the current practice of (verbally) opting-out (WS1/4, WS1/5). Although not implemented in state-of-the art consumer devices, such opt-in systems have been suggested by prior work. For instance, Gurrin et al. [GAJ$^+$14] implemented an opt-in system based on face detection and face recognition for lifelogging: their 'negative face blurring' approach obscures all image areas identified as faces, except for those of known individuals (e.g., family members of the user). These approaches raise, however, an additional issue, the participants deemed unsolvable: *"We try to protect this right [privacy] by having our pictures [...] scanned, but then it becomes even more so transparent whether we are there or not"*.

Responsibility and Perspective

In WS2 participants were specifically encouraged to reflect on responsibility. All groups in WS2 deemed both users, and legislation responsible. Discussed solutions included bans (e.g., in hospitals), but put a stronger focus on envisioned certification and licensing procedures. Two of the four groups suggested to put device manufacturer under the obligation to provide means to protect bystander privacy: *"We also consider the legislator here, who must approach the manufacturer, because [the latter] is the one who must ultimately implement it [privacy protection]"*. Only one group (WS2/4) found bystanders to be responsible for their privacy protection themselves: *"because if you leave the house, you have to expect to be photographed and if you enter a town hall have to live with the fact that they are under surveillance"*. This is notable, as prior work found bystanders to vocalize a desire to actively protect their privacy [DDK14]. We believe that these results are not contradictory, but rather a result of our participants taking a more macrosocial perspective as opposed to the individual (bystanders') perspective in Denning's work. This change of perspective might be facilitated through the use of the card deck and/or the specific task they were given.

Limitations

The design-in-use studies presented in this section provide a first estimate of how the Privacy Mediation Cards can be used to facilitate participatory design sessions and what solutions are produced by the participants. We reported and discussed solutions generated by students with varying backgrounds in two workshops with 60, respectively 90 minutes of discussion time each. While we found the cards to be well understandable and provide sufficient background to our participants, who all had at least university entrance qualification, the level of abstraction and simplification might not be suitable to involve all relevant groups of stakeholders, e.g., cognitively impaired persons. It is thinkable however, to re-design the existing card deck to create a second version using simplified language. Similarly, some stakeholders might have a higher specialization level or expertise than the participating students, e.g., politicians, or experts on privacy law. Thus, using the card deck in a workshop with these groups of stakeholders (i.e., in a setting similar to the Bahn Tower Workshop [Tae17]) might produce different, potentially even more controversial, results. To account for this, we evolved the card deck util pre-press stage and provide it as print-on-demand via MPC [Koe19]. This will allow the card deck to be used in additional workshops beyond our design-in-use studies. Furthermore, we did not evaluate the Privacy Mediation Cards in combination with other co-design methods; an approach which might indeed be highly beneficial, specifically for longer workshops or seminars. We decided to leave this to future work in favor of an in-depth look into the design challenges identified through the design-in-use studies: unadorned, preparation-free bystander controls, and design of non-LED status indicators.

4.1.5 Summary

Privacy concerns negatively influence the social acceptability of body-worn cameras. We presented a card deck, the Privacy Mediation Cards, that facilitates addressing this issue in participatory design sessions. Our results indicate that the card deck helps participants with varying (technical) background to find common ground and to successfully come up with design solutions. During the presentation of their suggestions, our participants highlighted the need to balance device functionality and bystander privacy and stressed practicality and comfort as requirements. A qualitative analysis of the participatory design sessions furthermore surfaced two design challenges, namely (1) the provision of unadorned, preparation-free means of communication for obtaining bystanders' privacy preferences, ideally before or during recording, and (2) the design of noticable privacy indicators that can be easily understood by bystanders (e.g., without remembering color codings). We will address those two challenges in the following Sections 4.2 and 4.3.

4.2 Granting Control: Gestures as Consent Mechanisms

Gestures are typically understood as perceivable actions with communicational intent [Ken86]. In HCI, gestures are widely employed and highly valued as interaction technique, not only, but also because they allow to implement the so-called "come-as-you-are" paradigm (c.f., Triesch et al. [TvdM98]). As highlighted by Karam and schraefel, *"almost every form of human gesturing that is possible can be seen in the literature as a means of providing natural and intuitive ways to interact with computers across most, if not all computer application domains"* [Ksm05]. In addition, technological achievements in terms of gesture recognition are promising, and allow to expect high precision gestural input to soon become available in day-to-day life [CSK+19; WSL+16; RA15; SPS+15]. Considering the challenge of providing unadorned and preparation-free bystander controls, gestures consequently suggest themselves as one potential solution. Moreover, prior work has provided evidence that the public use of gestural commands as opposed to voice commands is socially more acceptable [RdSC08; Wil12]. For these reasons, we decided to explore free-hand gestural Opt-in and Opt-out, which had so-far only been covered from a technical perspective [JP14; SZH17; SZH18]. Thus, in contrast to prior work, this section elaborates on the *choice of suitable gesture vocabularies* for privacy mediation, including the social acceptability of candidate gestures for Opt-in and Opt-out.

Figure 4.6: Free-hand gestures might enable device-less communication of privacy preferences. We collected various gestures for Opt-in (left) and Opt-out (right) in an elicitation study.

4.2.1 Contributions and Related Work

Bystanders of mobile camera devices, such as body-worn cameras, often have no option of providing consent or expressing their disagreement with being recorded, except by directly addressing the camera user. This is however, not always possible, especially since "always-on" cameras, such as life logging devices, or smart glasses, are often ambiguous about their recording status.

Our work aims to give back control to the bystander, and enable them to consciously decide their recording preference. As suggested by Denning et al. [DDK14], we distinguish between two types of consent mechanisms:

> **Opt-in** bystanders are by-default anonymized, e.g., by blurring their faces, or are removed from the imagery. If they wish to be recorded they have to explicitly provide consent.
>
> **Opt-out** in the default case, everyone is recorded. Any bystander who wants to be excluded from the recorded imagery has to explicitly express their disagreement.

Opt-in and Opt-out procedures that rely on wireless communication, using BLE[3] or Wi-Fi, or visual markers (c.f. [SMM+09; SZH17]), require the bystander to own a particular device or token. Blocking technologies, such as Yamada's "Privacy Visor" or Harvey's "CV Dazzle" also require the bystander to wear tags, particular accessories [TPS+05; YGE13] or make-up [Har12]. These approaches however, require bystanders to own and use specific technologies. In contrast, mechanisms following the "come-as-you-are" paradigm do not require additional adornments on the bystander's side. They could provide him/her with control over the image, e.g., using gesture or voice commands. With the increasing popularity of Voice User Interfaces (c.f., Porcheron et al. [PFR+18]), voice commands, such as "Stop recording!", or "Camera off", might be considered an intuitive choice. However, Reis et al. [RdSC08] report that the user's willingness to use voice commands decreases with an increasing number of strangers in the surroundings. Thus, requiring bystanders to use speech to opt-in or opt-out of an "always-on" camera's recording might create barriers: Williamson et al. [Wil12] found gesture-based interactions to be considered more socially acceptable than voice-based interactions when interacting in public. Thus, in this section, we explore a "come-as-you-are" approach where bystanders utilize **free-hand gestures** as Opt-in, and Opt-out mechanisms.

The use of gestural interaction between primary users and their smart glasses has been explored for both hand-to-face [SEI14] as well as free-hand gestures [HJO+16]. In contrast, (gestural) interaction between secondary users (e.g., bystanders) and a primary user's body-worn device (e.g., their Smart Watches [PRJ15] or Virtual Reality glasses [CM17]) has not been fully explored. Our work contributes to closing this gap.

[3] BLE, abbreviation for Bluetooth Low Energy

While a comprehensive line of research has investigated the usage [HLB+10], social acceptability [RB09; RB10a; AHI14] and learnability [ACT+15] of free-hand gestural human-machine communication in public, using gestures for privacy mediation with smart glasses and/or body-worn cameras has only sparsely been covered. Shu et al. [SZH17; SZH18] explore visual tags, gestures, and their combinations, and Jung et al. [JP14] suggest an off-the-record gesture for imposing privacy preferences to a third person's body-worn camera. Both however, do not delve into the choice of gestures. Prior work targeting other Opt-in and Opt-out scenarios (e.g., Barhm et al. [BQQ+11]) are also not conclusive about what gestures are suitable, i.e., applicable, easy to learn and execute, and unambiguously distinguishable in a variety of contexts.

We contribute the results of a gesture elicitation study (N=15) exploring options for free-hand Opt-in and Opt-out gestures, as well as results of a large-scale online survey (N=127) tackling ambiguity, understandability, representativeness, social acceptability and comfort. In light of our findings, we discuss the selection of Opt-in and Opt-out, and critically reflect on the concept of privacy mediation using Opt-in and Opt-out concluding with directions for future work.

4.2.2 Experiment 1: Elicitation Study

In our work, we employ Kendon's [Ken86] definition of gesture as a movement that is intended to convey information. Particularly, we explored hand movements suitable for encapsulating "Opt-in" or "Opt-out" intent. In order to collect as many potential candidates for Opt-in and Opt-out gestures, we conducted a guessability-style elicitation study [WAR+05]. This method has been successfully used in prior research [PLH+14] to generate easy to learn and remember gesture vocabularies. Moreover, it involves users in the early stages of concept development.

Method

After granting informed consent, participants filled out a brief demographic questionnaire that also assessed their experience with free-hand gestural interaction and symbolic languages such as international sign language, referee hand signals, and diver communications. Subsequently, participants were invited to envision and perform potential Opt-in, and Opt-out gestures. The Opt-in and Opt-out principles were visualized using explanatory cards that contained a textual and graphic description. The order of Opt-in, and Opt-out, respectively, was randomized between participants based on a lottery system. The gestures were video-recorded for further analysis. The guessability session was followed by a brief exit questionnaire, where participants reflected on Opt-in or Opt-out procedures in different hypothetical real-world situations. We post-processed and anonymized (e.g., blurring faces) all videos directly after the session and deleted the raw images. These procedures were approved by our institute's internal review board.

Participants

We recruited 15 unpaid participants (10m, 5f, 0d) via campus mailing lists and social networks. They were aged between 24 – 61 (M=28, SD=9) years. The majority of participants were students in different majors, including computer science, education, biology, and social sciences. Three of them were employees.

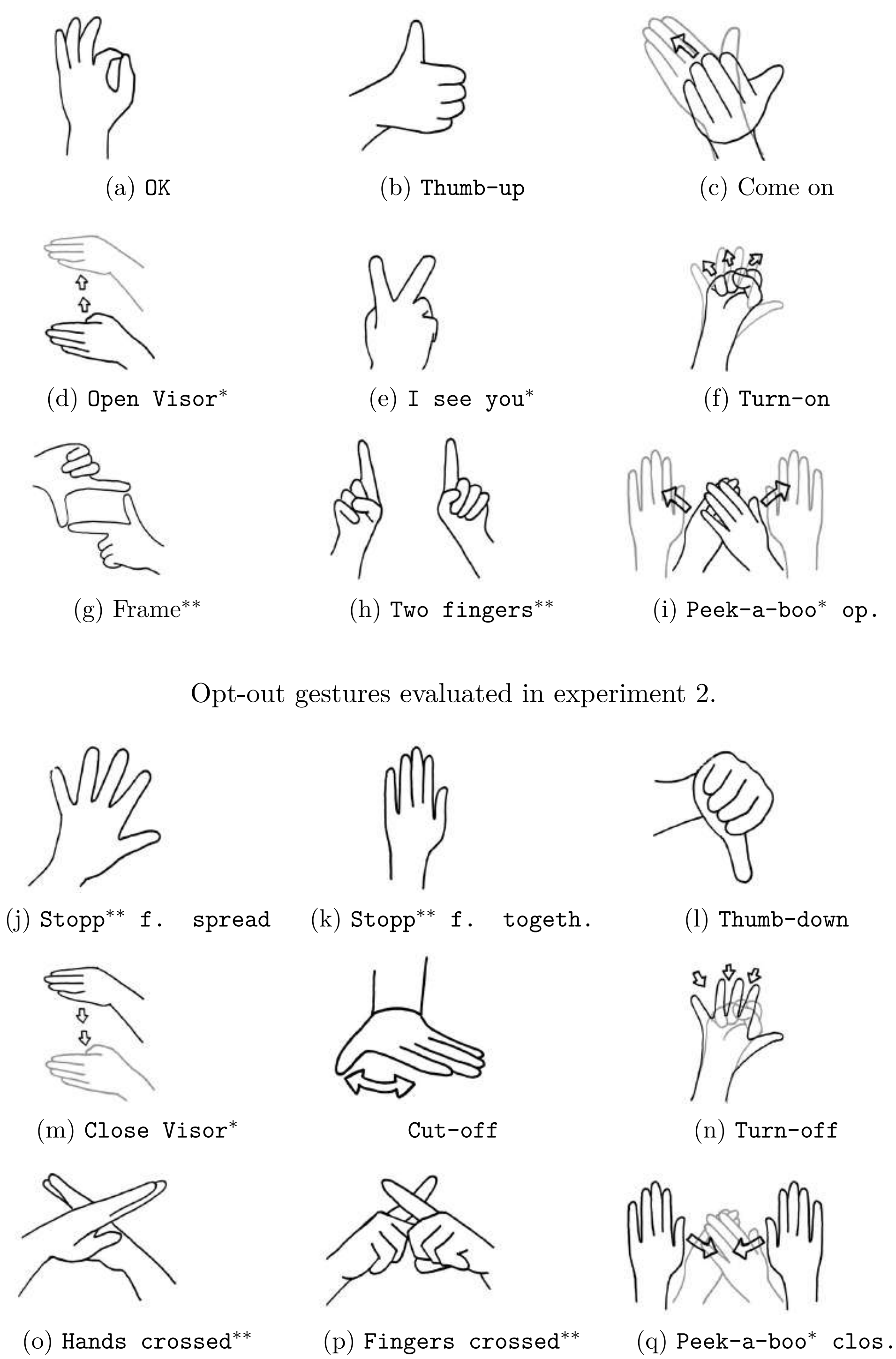
Figure 4.7: Our participants suggested dynamic gestures that encode information in the direction of movement: e.g., chin to forehead: Opt-in (middle), forehead to chin: Opt-out. Alternatively, concatenations of static gestures might have a different meaning depending on the order in which they are performed: fist opening: Opt-in (left), open hand closing to fist: Opt-out.

Results

We collected 94 gesture samples in total where each participant suggested between 4 and 9 (M=6 , SD=1) distinct gestures. In the following subsections we delve into these gestures, and discuss underlying metaphors and analogies. After removing duplicates and grouping similar gestures, we obtained 60 distinct gestures, 32 of which were suggested for Opt-out and 28 for Opt-in. Participants suggested both, static (Figure 4.6) and dynamic gestures (Figure 4.7). For some gestures, such as `Peek-a-boo`, shown in Figure 4.7 (right) we recorded both one-handed and two-handed variants. Some also suggested combinations where multiple static gestures were sequentially linked, e.g., `I see you` followed by `Thumb-up` or covering both eyes followed by a `Thumb-down` movement.

While envisioning suitable gestures for Opt-in and Opt-out, most participants utilized metaphors or analogies. Opt-in was used synonymous with *agreeing* (e.g., Nodding, or the `Thumb-up` gesture), and Opt-out with *disagreeing* (e.g., shaking ones head, or `Thumb-down`). Other suggested gestures borrowed movements, artifacts or postures from reality: e.g., the "picture taking" movement that imitates pressing the camera trigger, or the `Frame` gesture that mimics the physical dimensions of a photograph. The `Open visor` and `Close visor` gestures simulate the actions performed on a motorcycle helmet's visor or an ancient suit of armor. Aptly, participants used the human eye as a metaphor for the camera *seeing and not seeing*. They suggested multiple gestures covering and uncovering the eyes, the face (e.g., `Peek-a-boo`), or directly referring to the eyes (e.g., `I see you`, Figure 4.8). In conclusion, illustrating the abstract concepts of Opt-in and Opt-out using real-life analogies might support intuitive understanding.

Opt-in gestures evaluated in experiment 2.



(a) OK (b) Thumb-up (c) Come on

(d) Open Visor* (e) I see you* (f) Turn-on

(g) Frame** (h) Two fingers** (i) Peek-a-boo* op.

Opt-out gestures evaluated in experiment 2.

(j) Stopp** f. spread (k) Stopp** f. togeth. (l) Thumb-down

(m) Close Visor* Cut-off (n) Turn-off

(o) Hands crossed** (p) Fingers crossed** (q) Peek-a-boo* clos.

Figure 4.8: Overview of evaluated Opt-in gestures (top) and Opt-out gestures (bottom). Some gestures employ metaphors that refer to the eyes or face. Thus these are mostly carried out in front of the face (indicated as *, faces not shown for visual clarity). Dynamic gestures are indicated using arrows, where the grayed out hand posture indicates the end of the movement.

*) typically carried out in front of the face.
**) might be carried out either in front of the face or chest

Wherever possible, participants tried to come up with complementary pairs of Opt-in and Opt-out gestures. For concatenated (dynamic) gestures this often meant a reversal of order (c.f., `Turn-off` and `Turn-on`, Figure 4.7, left). For kinematic gestures, that indicated a directional movement (e.g., up for Opt-in) they simply showed the same movement in the opposite direction (e.g., down for Opt-out). Similarly, static gestures such as `Thumb-up`, had a reverse `Thumb-down` corollary. These observations indicate, that pairs of Opt-in/Opt-out gestures referring to antithetical concepts, have complementary kinesthetic counterparts. These kinesthetic pairs might be preferred by users, and also easier to learn and remember.

Figure 4.9: Sample frames taken from the animated gesture sequences used in the online survey. To clearly delineate start and end of each gesture, all rendered animations started in the same pose (A). Then, one of the pre-selected 18 gestures (e.g., B, C, D, E) was performed by the virtual character before ending with the start pose (A) again.

4.2.3 Experiment 2: Online Survey

How a gesture is interpreted may largely vary between regions, e.g., within Europe (c.f., Morris [Mor79]). To better understand how gestures are interpreted in western regions, we conducted an online survey with 127 participants from Europe and North America using a subset of gestures from the elicitation study. We selected the 18 most frequently used Opt-in and Opt-out gestures (Figure 4.8). In the cases where participants suggested a one-handed and a two-handed version of the gesture, we included the more frequently used version in the survey.

Method and Study Materials

We used abstract renderings of a virtual, androgynous character to showcase the gestures. We avoided real-world footage, to prevent cultural or gender bias. Each of the 18 gestures (9 opt-in, 9 opt-out) was named at least twice during the elicitation study. We generated a three seconds (72 frames) video clip comprising the virtual character performing each gesture (c.f., Figure 4.9). Static gestures were held for 7 frames; dynamic gestures were performed in 28 frames. To clearly delineate start and end of each gesture, the character started and ended in the same position, with both hands casually on the side. The video clips were looped indefinitely in the online questionnaire, to allow the participant to thoroughly judge each gesture. All clips were piloted and tested independently by two researchers other than the authors.

The online survey first gathered demographic information and participants' prior experiences with gesture-based languages, manual communication (e.g., ASL[4]), and gesture-controlled human-machine interfaces. Subsequently, they were presented with the gesture videos in randomized order. Participants were asked to explore alternative meanings for each gesture (*"What does the gesture shown in the video above mean to you?"*) and objectively decide whether it meant an "Opt-in", "Opt-out", or *"something completely different"*. Then, on a 7-pt Kunin Scale [Kun55], they were asked to rate the gesture's representativeness for Opt-in, and Opt-out as well as its social acceptability (*"How acceptable would it be to perform the presented gesture in public?"*). They were also asked to indicate their confidence in performing the gesture in public (*"How comfortable would you feel performing this gesture in an everyday public setting, such as a busy sidewalk?"*, c.f., [Wil12].

Participants

Participants were recruited via quota-sampling on Prolific[5]. Overall 127 participants (68m, 59 f, 0d) from Europe (63, 50%), and North America (64, 50%) took part in the study. Table 4.5 lists the country of origin (COO) and country of residence (COR) as an indicator of cultural background. Participants were aged between 18 and 71 (M=34, SD=12). Nineteen (15%) of them indicated that they had experience with manual communications (e.g., diver communications/RTSC); 11 (9%) of them knew ASL[6]. Only few had ever used free-hand gestures to operate a human-machine interface such as the Microsoft Kinect (13, 10%).

Around half the participants had a university or college degree (66, 52%), and a few (3, 2%) had doctorate/postdoctoral lecture qualification as highest level of education (ISCED[7] level 6 and above). Twenty-four (19%) participants had obtained a High School Diploma or Associate degree (level 5), 14 (11%) had a vocational or technical school diploma (level 4), and overall 18 (14%) indicated levels of 3 or below.

4.2.4 Results

Overall, 71 participants (56%) left optional qualitative comments at the end of the questionnaire. In this section, we selectively report comments on specific gestures together with the quantitative results. Other quotations, e.g., concerning ethical or social issues are included in the discussion section.

[4] ASL, abbreviation for Americal Sign Language
[5] Prolific, `https://prolific.ac`, accessed 2019
[6] American Sign Language, c.f., `https://www.handspeak.com`, accessed 2019
[7] International Standard Classification of Education (ISCED), `http://uis.unesco.org/en/isced-mappings`, accessed 2019

Country	Participants'	
	COR*	COO**
US	59(46%)	58(46%)
Italy	21(17%)	19(15%)
UK	12(9%)	9(7%)
Spain	8(6%)	7(6%)
Germany	6(5%)	6(5%)
Canada	5(4%)	6(5%)
Netherlands	4(3%)	4(3%)
Ireland	4(3%)	3(2%)
Others	8(6%)	15(12%)

*) In which country do you currently live and work?
**) In which country did you grow up?

Table 4.5: Participants were recruited via quota-sampling from North America and Europe. Number of participants per country of residence (COR) and country of origin (COO).

Meaning and Ambiguity

Participants listed 0 to 7 distinct meanings for each proposed gesture. We grouped the meanings and removed all occurrences of "Opt-in" (n=16) and "Opt-out" (n=39) from this part of our analysis to mitigate interviewer bias, since they might not reflect how the gestures would have been understood outside our study.

Unsurprisingly, many of the gestures marked as Opt-in by our participants from experiment 1 showed an inherent positive connotation, e.g., `Thumb-up`: "OK"(n=75), "Good"(n=41), "yes"(n=24). Many Opt-out gestures were inherently negative, e.g., `Fingers crossed`: "Stop" (n=48), "No"(n=27).

As suggested during the elicitation study, the `Frame` gesture was understood as a metaphorical representation for "Picture taking" "Photography" or "Camera" (n=117). Additions, such as "look at my smile" and "I feel sexy" indicate that the gesture communicates a positive attitude towards photography. The `Two fingers` gesture, which the participants in experiment 1 also intended to represent the boundaries of a frame or picture, was understood by some participants ("Picture taking", n=24), but oftentimes misunderstood as "Deer" resp. "Animal with horns" (n=16) or directional command: "Up" (n=13). While the `I see you` gesture was understood as a reference to eyes and/or watching (n=88), participants were indecisive whether the gesture referred to an ego perspective "I am watching what you do" or a third person "Look at me".

While thirty participants assigned "Hiding" or "Hide" to the closing variant of the `Peek-a-boo` gesture (n=30), the opening variant was perceived as confusing: participants named "Hide" (n=8) as well as open (n=11), or stated "Nothing" (n=9) or "No idea" (n=11). Similarly, participants were inconclusive about the `Turn-on` and `Turn-off` gestures, where they suggested (amongst others) "Vomit", "Bad breath", "Grabbing", and "Stop talking". This ambiguity was also reflected in the lower understandability and representativity ratings (see next section) of these gestures.

Understandability and Representativeness

Participants perceived the `Thumb-up` gesture as most representative (Mdn=7, SD=1.3, significant[8] with $p<0.01$), and a large majority interpreted it as Opt-in (110, 87%). This leads us to conclude that it is also well understandable as Opt-in gesture, along with the `Frame` (80%), `OK`[9] (80%), and `Come on` (74%) gestures. Similarly, the `Thumb-down` gesture was rated most representative (Mdn=7, SD=1.8) and clearly understood as Opt-out (79%). However, the gestures `Hands crossed` (Mdn=6, SD=1.7) and `Fingers crossed` (Mdn=6, SD=1.7) were also equally well understood (both 80%). There was no significant difference with regard to representativeness between `Thumb-up` and the other two gestures, `Hands crossed` and `Fingers crossed`.

Surprisingly, both `Stopp` gestures, which had been suggested most frequently (10 times) in experiment 1, underperformed amongst the static Opt-out gestures with regard to representativeness (both Mdn=5, SD=1.7), and understandability (c.f., Figure 4.10), where the version with spread fingers (76%) was slightly harder to understand than its relative with closed fingers (71%). Dynamic gestures were not generally rated less representative then static gestures. However, they were significantly[10] more often misinterpreted which points to a lack of understandability: χ^2 (8, N = 18) = 35.2 , $p<0.05$. This might partially be attributed to their novelty: *"I think the obvious gestures would be more efficient, but I think the hand going up or down the face would be cool if it's clearly established which means which. I saw it as the hand going down would be covering the face and the hand going up would be 'opening' up the face to opt-in"* (P45). Nevertheless, dynamic gestures that encode "Opt-in" respectively "Opt-out" in a directional movement, might also require more attention, and cognitive resources from the observer, and thus be harder to understand at a single glance.

Social Acceptability and Comfort

In general, participants stated that they would feel comfortable when performing the suggested gestures in public (av. Mdn=5.2), and that the suggested gestures

[8] Friedman Test plus Post-hoc Wilcoxon Signed Rank Test with Bonferroni Correction, $p<0.01$

[9] The "OK" sign can have a lot of different meanings, including agreement, well-being or perfection. It is an ancient gesture found in many cultures and also part of diver communications and ASL. Quite recently, the gesture has been appropriated by white supremacists who falsely promoted the gesture as racist hate symbol [ADL20]. We therefore recommend to exercise particular caution when making use of this gesture for system design.

[10] Chi-Square Test

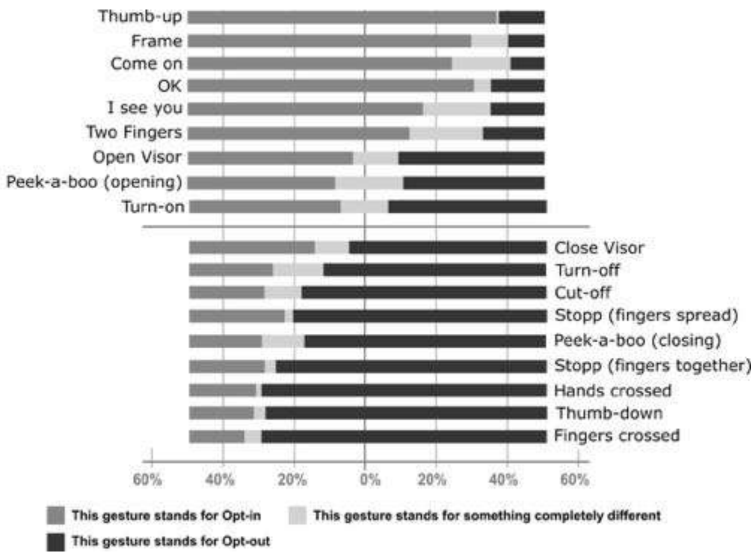


Figure 4.10: For each gesture participants decided whether they would understand it as Opt-in (green), Opt-out (red) or neither (grey). Gestures intended to be Opt-in are shown in the upper half, gestures intended as Opt-out in the lower half. The most distinct are the top (Opt-in) and the bottom (Opt-out) gestures.

were socially acceptable (av. Mdn=5.4). However, P62 also noted, that unfamiliarity with a certain gesture might have affected her rating: *"If I had seen people do them in public before I would have rated more so as highly acceptable [...]"* (P62).

On average participants rated the set of proposed Opt-in (Mean score =5.2, SD=1.1), and Opt-out (Mean score=5.3, SD=1.1) as equally acceptable in public; there were no significant[11] differences (Z=1.3, p=0.1, r=0.08). However, Opt-in gestures that did have a directionally complementary Opt-out gesture were rated significantly more acceptable than their counterpart: participants perceived the `Thumbs-up` (Mdn=7, SD=1.0) gesture as significantly more acceptable than the `Thumb-down` (Mdn=6, SD=1.5) gesture (Z=4.6, $p<0.05$, r=0.28), and would feel significantly more comfortable performing the `Thumb-up` gesture in public (Z=5.0, $p<0.05$, r=0.31). A smaller, but similar effect can be observed for the `Open Visor` and `Close Visor` (Z=1.8, $p<0.05$, r=0.1).

We did find no significant difference regarding acceptability for the `Peek-a-boo (opening)` and the corresponding `Peek-a-boo (closing)` gesture (Z=1.5, p=0.07, r=0.01). This might, however, be attributed to the lack of understandability (c.f., Figure 4.10) and representativeness (Mdn=3) of the uncovering (opening) variant along with 24 (19%) participants indicating that the gesture stood for neither Opt-in nor Opt-out. This matches that, from the list of collected meanings (see

[11] Wilcoxon Signed Rank Test for paired samples

above) the gesture seems not to have a strong positive connotation. The same applies to the `Turn-off` and `Turn-on` gestures (Z=1.5, p=0.07, r=0.1) which are, as discussed above, also more ambiguous than the other proposed gestures.

With regard to comfort and acceptability there were no differences between static and dynamic, and one-handed as well as two-handed gestures. However, two participants also commented on the practicability of two-handed gestures: *"I don't think two-handed gestures are a good idea. What if you're carrying something (e.g., groceries)?"* (P57).

4.2.5 Discussion

Designing command sets for gesture-based interaction is a well researched area in HCI. Quality criteria for gesture vocabularies include *cognitive*, *articulatory*, and *technological aspects* (c.f., Lenman et al. [LBT02]). The main focus of this work were *cognitive aspects*, i.e., which gestures are perceived as natural and intuitive (c.f., Barclay et al. [BWL+11]) in a certain context: does a gesture that was intended as Opt-in, or Opt-out, respectively, inherently make sense to the user? Would (s)he feel natural using it for opting-in or opting-out?

In the following we discuss if and how a decision for a gesture set for privacy mediation, comprising an Opt-in, and Opt-out gesture, could be made based on the results of our experiments.

Selecting Gestures

We demonstrated that it is possible to find gestures that are (1) representative for Opt-in and Opt-out, as well as (2) understandable and easy to interpret. Our results show that some of the evaluated gestures were already beset with meaning, which increases ambiguity but also makes them easier to interpret. On the other hand, existing gestures that are frequently used in other contexts (e.g., `Thumb-up`) might cause false positive interpretations. P33 highlights that *"several [gestures] did not appear to have any generic use. It would be difficult to find an action that is not used in everyday life for opting in and out [...] without having unintentional signs sent to the camera operator"*. P31 was worried *"[..] they may opt-in accidentally"*.

Consequently, when designing systems that intend to use Opt-in and Opt-out gestures, we should carefully consider whether to re-appropriate an existing gesture or establish a new gesture. To envision new gestures for Opt-in and Opt-out, metaphors and analogies associated with photography (e.g., the `Frame` gesture) can provide a starting point. Establishing a new gesture might succeed for widely deployed mainstream systems, but be difficult for niche or prototypical applications.

Furthermore, our results indicate that gestures with a positive connotation (1) would typically be used as Opt-in gesture, and (2) would be perceived more socially acceptable than a potential counterpart with a negative connotation (i.e, Opt-out). Our participants indicated that, in public, they would feel more comfortable performing an affirmative gesture, such as `Thumb-up`, than performing a dissenting gesture, such as `Thumb-down`. In the context of privacy mediation this is problematic. Similarly to acquiescence effects, secondary users (i.e., bystanders) might be hesitant performing an Opt-out gesture, if they feel uncomfortable doing so, and thus silently accept privacy infringements. The performative nature of gestures (c.f., [Wil12]) might add up to this effect, as P43 states *"People who want to opt out should only have to do something subtle, they shouldn't have to make any kind of grand, flamboyant gesture to opt out"* (P43). In consequence, to avoid unwanted bias and acquiescence, gesture sets for Opt-in and Opt-out would have to be consciously designed and carefully selected, as well as critically (re-)evaluated in-situ.

Ethicality and Legal Issues

Multiple participants raised the question whether it should not rather be the user, instead of the bystanders who takes care of privacy protection: *"Placing the onus of having to opt out on people who may not even be aware of the recording taking place is inadequate"* (P63). This issue has also been tackled by Denning et al. [DDK14] who also discussed the burden of registering, and noted that a number of their participants expressed a desire for camera blocking technologies. Participant 21 doubts *"whether such devices with just an 'opt-out' mechanism would even be legal"* (P21). In fact, the General Data Protection Regulation (GDPR – EU 2016/679 [Reg16]), which came into effect in May 2018, requires "privacy-by-default", i.e., bystander privacy would have to be implemented in all cases, except where (s)he had explicitly Opted-in. In practice however, most body-worn cameras do not provide any privacy mediating procedure. Thus, to date the de facto procedure is Opt-out, i.e., (verbally) asking the device user to turn the camera off.

In contrast to blocking or wirelessly communicating artifacts e.g., BLE tokens, that allow secondary users to remain *passive*, gestures would require the bystander to *proactively* Opt-in, or Opt-out. P36 imagines *"I cannot imagine having to do this either way. There is getting to be a little too much stress in our everyday walking around. I don't like the idea of the glasses with cameras"*. P21 adds *"You would be forced to constantly be aware of any person wearing such a device and take care to always opt-out"* which they would perceive as inconvenience.

Alternatively, body-worn cameras might react automatically and adjust to contextual privacy requirements (e.g., based on location [TKC+14], content [KTC+14], or activity [SKH+19]), thus taking the burden of both, primary and secondary users. Considering individual contexts could be beneficial, as legally (e.g., in

GDPR) it strongly depends on the situation, whether the use of a body-worn camera would be unregulated (e.g., at home), based on proportionality (e.g., in (touristic) city centers), or prohibited (e.g., in a clinic). In addition, how users and bystanders perceive privacy is also highly individual (c.f., Price at al. [PSC+17]). Thus, combining both, manual and automatic, approaches could be highly advantageous: utilizing a default automatic, context-sensitive approach could provide comfort and reliability. A gesture-based approach (e.g., to Opt-in) for special cases or more individual and granular control would increase flexibility, and offer a viable control mechanism to bystanders. In this context, any implementation would have to accept both, Opt-in as well as Opt-out gestures, to provide flexible and reversible choices (c.f., Nielsen et al. [Nie94]). With our work, we demonstrated that complementary gestures for Opt-in, and Opt-out can be found, e.g., by reversing the order or direction of movements in dynamic gestures or altering the directionality of deictic gestures. Nevertheless, our qualitative results also highlight that the moral and legal implications of smart glasses and body-worn cameras, as well as GDPR's implications for such camera devices, are not talked through yet.

Limitations

Our work provides first assessment of which gestures are representative for Opt-in, and Opt-out, in the context of smart glasses with integrated "always-on" cameras. As the choice of the "right" gesture, might not only depend on the individual gesture, but also on the interaction design (default or specialized use case) and the dissemination of the intended application or device, we do not explicitly propose a concrete set of gestures. Moreover, our analysis is most likely limited to how the proposed gestures are perceived in western regions. However, future work could fill this gap building upon our methodology and using our study materials. Due to timing and format of the online survey, we did not test for rememberability and appropriation, two factors that might also affect the effectiveness of Opt-in, and Opt-out gestures. Nevertheless, our results provide the necessary ground work for systems design and future long-term studies.

Furthermore, our work only considered gestures for Opt-in/Opt-out. In practice, privacy preferences might not be binary, but require more granular distinctions. This aspect is relevant, as – in addition to privacy-by-default and privacy-by-design – the GDPR names the granularity of consent as key principle. Our work can serve as a baseline and starting point for creating more extensive gesture vocabularies including granular consent, e.g., defining consent for recording, but no consent for sharing. In addition, the GDPR also requires consent to be informed, which is not covered in this study. However, design solutions for active communication of presence and actions of body-worn cameras have been suggested by Egelman et al. [EKC15], and explored in our own follow-up prior research (Section 4.3).

4.2.6 Summary

We explored Opt-in and Opt-out gestures for privacy mediation with body-worn cameras based on a guessability-style elicitation study. Then, we evaluated nineteen gestures in a larger scale online survey, where we investigated ambiguity, representatives, understandability, as well as social acceptance and comfort. Our work supplements existing work [BQQ+11; JP14; SZH17] and contributes a set of evaluated gestures for Opt-in and Opt-out that can motivate gestural interaction in future prototypes of privacy mediating systems. Our results indicate that it is feasible to create a gesture vocabulary for Opting-in and Opting-out of camera recordings. Systems employing gesture-based Opt-in and Opt-out need to be designed in a way such that they (1) employ gestures that are not a priori beset with meaning, but can be easily learned and associated with "recording" or "picture taking"; (2) offer complementary gestures for both, Opt-in, as well as Opt-out; and (3) employ gestures that are extendable (e.g., through sequential linkage) to account for the need for granular, non-binary privacy preferences.

Moreover, our research empirically supports the maxim of designing for privacy protection as default (i.e., Opt-in), as Opt-out gestures often have an inherent negative connotation and may cause acquiescence effects. Nevertheless, future work will have to discuss the practicality of providing and obtaining informed consent in the context of ubiquitous (body-worn) cameras. We envision that, instead of being an exclusive method for privacy mediation, gestural Opt-in, respectively Opt-out could extend and supplement a less interactive e.g., automatic, context-sensitive approach implementing privacy-by-default, and privacy-by-design.

4.3 Providing Notice: Privacy Indicators beyond Status LEDs

Privacy notices are feedback (or feedthrough) mechanisms that communicate personal data gathered and processed by a system [BS93; EGA+15]. In the case of body-worn cameras they should ideally make both, primary and secondary users, aware of the camera's status or modus operandi. This is challenging, as, in contrast to traditional, hand-held photography devices, body-worn or environment placed cameras are supposedly "always on", i.e., spectators are limited in their ability to tell whether the device is idle, recording, or taking a picture, as they cannot infer this from the photographers body posture. While privacy indicators are well researched in the context of HTTPS web browsing [RBN+13; MdLS11], state-of-the-art body-worn cameras (c.f. Figure 4.11) either do not provide any indicators or rely on binary information from point lights (status LEDs) that can be easily overlooked, misunderstood, or hidden.

Figure 4.11: For bystanders it is not always easy to determine whether state-of-the-art body-worn cameras are recording them: some devices, such as Google Glass Explorer Edition (left) or the Narrative Clip (2nd from the left) do not provide any status indicator or privacy notice. Other devices, e.g., Snap's Spectacles (2nd from the right), provide LED indicators. However, those can be easily overlooked, misunderstood, or hidden, e.g., by applying stickers (right).

Hypothesizing that the commonly used status LED is therefore no optimal status indicator for a body-worn camera (due to being not sufficiently understandable, noticeable, secure and trustworthy), this section explores design requirements of privacy notices for body-worn cameras. Following a two-step approach, we contribute incentives for design alternatives to status LEDs: Starting from 8 design sessions with experts, we discuss 8 physical design artifacts, as well as design strategies and key motives. Finally, we derive design recommendations of the proposed solutions, which we back based on an evaluation with 12 User Experience (UX) and HCI experts.

4.3.1 Contributions and Related Work

Non-existent or poor feedback mechanisms are an everyday, practical privacy problem [BS93; DGdL+04] that also deprives bystanders of the possibility to react or possibly object to being captured. Additionally, even though actual device usage might not be a privacy violation as such (e.g., having the camera turned off), the presence of a camera that is (potentially) "always-on" is perceived as a threat to privacy [KKM15] and may intensify "surveillance pressure". This has a negative effect on both, the spectator's and the user's social acceptance (c.f. [BMC+09; MAM+10]), which can cause the user to avoid using or wearing the camera device, potentially sacrificing its assistive function (c.f., [PAF+16]). Thus, we base our research on the assumption that privacy notices for body-worn cameras need to deal with the following user (and bystander) concerns:

> **Situation Awareness** Is the bystander aware whether a camera device is present? Is (s)he able to verify whether this device is on or off? Does (s)he know what data is being recorded, for what purpose and by whom?
>
> **Justification** Does the device show that I (the user) do not have any dishonest intentions? Does the device communicate when the camera is worn, but not turned on? Does the device communicate when the camera is turned on (e.g., for tracking) but is not persistently storing data?

In addition to potentially conflicting with penal and civil law, cameras that facilitate subtle recording violate privacy or privacy-by-design guidelines that demand **Openness** (OECD, [OD13]), **Notice** [Lan01], or **Visibility and Transparency** [Cav09], such that everyone involved should be able to verify what is captured and how their data[12] is handled. Providing adequate design solutions is a timely issue, as the recent revision of the EU General Data Protection Regulation [Reg16] obligates manufacturers to implement "privacy-by-design" for both, users and potential bystanders. The directive does not detail how this privacy-by-design requirement shall be achieved. Thus, research in industry and academia will have to fill this gap by providing well thought-out procedures and design strategies.

Research Goals and Challenges

In order to satisfy the above-mentioned requirements, Openness [OD13], Notice [Lan01], and Visibility and Transparency [Cav09] for body-worn cameras, two design challenges need to be solved.

Challenge 1: Body-worn cameras should announce themselves and their actions in a noticeable, but not too obtrusive way (c.f., Flammer et al. [Fla16]).

Conveying knowledge about usage intentions is not only demanded by existing privacy regulations, but can increase social acceptance [KKM15]. In order to do so, privacy indicators need to show what information is used by the system [EKC15].

[12] Photographs potentially allow to identify depicted persons, and thus are typically considered as **personal data** under the EU Data Protection Directive 1995 and derived national regulations.

Challenge 2: Body-worn cameras should publicly communicate their purpose of use to bystanders, but not impair the user's privacy.

Our research goal is to tackle these challenges by contributing to a better understanding of the weaknesses of established design strategies – particularly status LEDs – and by highlighting novel design opportunities. This paper makes two contributions: First, we present eight physical artifacts that embed design strategies addressing the problems *noticeability*, *understandability*, *security*, and *trustworthiness*, and suggest alternatives to LED status lights. They may serve as inspiration or critical designs [DR01] to spark innovative thinking about privacy notices. Second, we discuss the used design strategies and derive design recommendations for privacy notices and privacy mediating procedures for body-worn cameras.

Related Work

While there exists an extensive body of literature on privacy notices for *primary users* while browsing the web [RBN+13; MdLS11], or using mobile phones [KCS13] or fitness trackers [GSF+16], only very few researchers have targeted *secondary users* (e.g., conversation partners) or third party, *incidental users* (e.g., bystanders, c.f. [ITA+06]). Systems implementing the negotiation of privacy preferences between device users and bystanders, similar to the "Privacy Dashboard" concept (c.f., Flammer [Fla16]) have been presented by Memon and Tanaka [MT14] and Aditya et al. [ASD+16]. Krombholz et al. suggest design guidelines based on three conceptual privacy-mediating technologies, a "privacy bracelet", a "privacy fabric", and a "privacy app" [KDS+17]. These conceptual scaffolds were used to better understand bystander privacy risks and explore options to communicate user-defined privacy policies. These systems all require bystanders to own a particular device (e.g., smart phone or token) and to pro-actively define and communicate their privacy preferences. Although the dissemination of smart phones and BLE devices is increasing, these approaches do not render notification and announcement mechanisms obsolete, as bystanders need to be made aware of potential privacy risks in the first place. Our work aims at closing this gap by investigating privacy notices that announce to the captured person if (s)he is being captured and what the captured data will be used for.

These kinds of announcement mechanisms have been discussed in an early work by Bellotti et al. [BS93] who proposed design solutions, such as the "confidence monitor" (a public display showing the captured imagery) and visual and audio signals. This work, however, is based on fixed-location cameras in a work environment and does not cover concerns triggered by today's body-worn cameras, e.g., "Is this footage going to be shared on social media?" (c.f., [HTA+14; DDK14]).

Moreover, our work is complementary to Schaub et al.'s [SBD+15] who propose a comprehensive design space for effective privacy notices taking into account all possible stakeholders, and account for timing, channel, modality, and control. They further discuss best practices for photo and video lifelogging. Their taxonomy, however, is based on literature research and state-of-the art consumer systems, and thus, limited to existing concepts and technologies. We extend their work by asking experts to develop and critically discuss ideas for novel approaches - that then may be classified according to their taxonomy. Flammer [Fla16] recommends a “Peacock Design” principle where information about a device and a user’s actions with it are announced to bystanders. This could be achieved using actuators or physical gestures and signs to replace the current “invisible and unobtrusive” approach. However, they also highlight that announcement mechanisms should not compromise the users’ impression management (e.g., being too flashy), which will require novel design solutions. To the best of our knowledge, no design strategies other than status LEDs have been suggested so far in literature or applied by industry. With our work we go beyond those conceptional considerations by presenting design artifacts to serve as inspiration or starting points, as well as concrete design recommendations.

Problem Description

In order to meet any of the above mentioned guidelines, body-worn cameras would require effective announcement mechanisms that indicate (at least) whether the camera in question is recording or idle. It would also be ideal to inform the subject(s) about the intention of the recording and the information being saved. One commonly used design strategy is the use of light indicators (LEDs), which for example, is used by GoPro cameras. Despite being wide-spread and ubiquitously integrated in various types of devices with build-in cameras, this design strategy is not optimal for various reasons.

First, LED status indicators are **not well noticable**. Portnoff et al. [PLE+15] were able to show that, when focusing on a primary task unrelated to the recording device, participants were unlikely to notice the webcam indicator light of their computer turning on. They further note that it is particularly challenging to help people notice a LED status indicator when they are in the same room but otherwise occupied. We believe that this also applies to wearable cameras, particularly when there is no direct interaction between the camera user and the bystander.

Second, status LEDs might **not always be fully understood** as they are not mentally linked to the camera [PLE+15]. Particularly, when integrated into a novel and unfamiliar device, bystanders might be unsure what a point light indicates [KKM15]. Despite point light displays providing a rich design space, their effectiveness is heavily influenced by learned conventions [HHH+12]. Since bystanders are not the primary users, they are often unaware of the meaning of a particular point light display. Therefore, colored LED indicators (e.g., red: recording, green: tracking) are unlikely to be optimal solutions.

Third, LED indicator lights are **not secure enough** as they are spoofable – i.e., they can be modified by their primary users to record secretly without signaling the bystanders. While hardware modifications, i.e., removing or de-wiring the LED require technical skills, LED indicators can also simply be masked[13] or painted over. In addition, malicious software might aim to take over the device and secretly record with the status LED turned off. Depending on the actual device's hardware, status LEDs are typically controlled through software, and thus could potentially be deactivated without simultaneously disabling the recording capabilities. Sophisticated counter strategies have been covered by IT Security research [MA16], but do not provide hundred percent protection. Aiming to prevent software attacks, other devices have the status LED hardwired in the same logical connection as the webcam. However, recent research has shown that attacks on hardwired status LEDs have also been successful [BC14b].

Since LED indicator lights are prone to various kinds of spoofing, they are often perceived as **untrustworthy** from a user's or bystander's point of view. Prior studies have indicated that users are often unsure about the actual mode of operation of the status lights [PLE+15], and due to the perceived risk of a security breach, users often cover the camera's lens [MSL+16]. In addition, even though actual device usage might not be a privacy violation as such (e.g., having the camera turned off), the presence of a camera that is (potentially) "always-on" is perceived as a threat to privacy: a turned-off indicator light does not entirely eliminate bystander concerns of being recorded [KKM15].

Summing up, LED status lights are not ideal for the design of effective privacy notices for body-worn cameras. Designing effective alternatives is challenging, as they would have to be *noticeable*, *understandable* without prior device-specific knowledge, *secure*, i.e. unspoofable and therefore also both, objectively and subjectively *trustworthy*.

4.3.2 Experiment 1: Expert Design Study

To address the research challenges (1) indicate camera presence and status, and (2) communication of the intention of use, we asked teams of experts to create concepts and design artifacts that support the user's need for *justification* and the bystander's need for *situation awareness*. This approach aims to explore requirements of privacy notices for body-worn cameras, which we believe is essential to reduce the lack of social acceptance of those devices. We do not limit privacy notices to the visual modality, but - following Schaub et al [SBD+15] - understand privacy notices as information output of interactive systems using any modality, including audio [94] and haptics [RKK97].

[13] How to modify & Black out Snapchat Spectacles, `https://www.youtube.com/watch?v=GRN3rRqol98`, accessed 2019

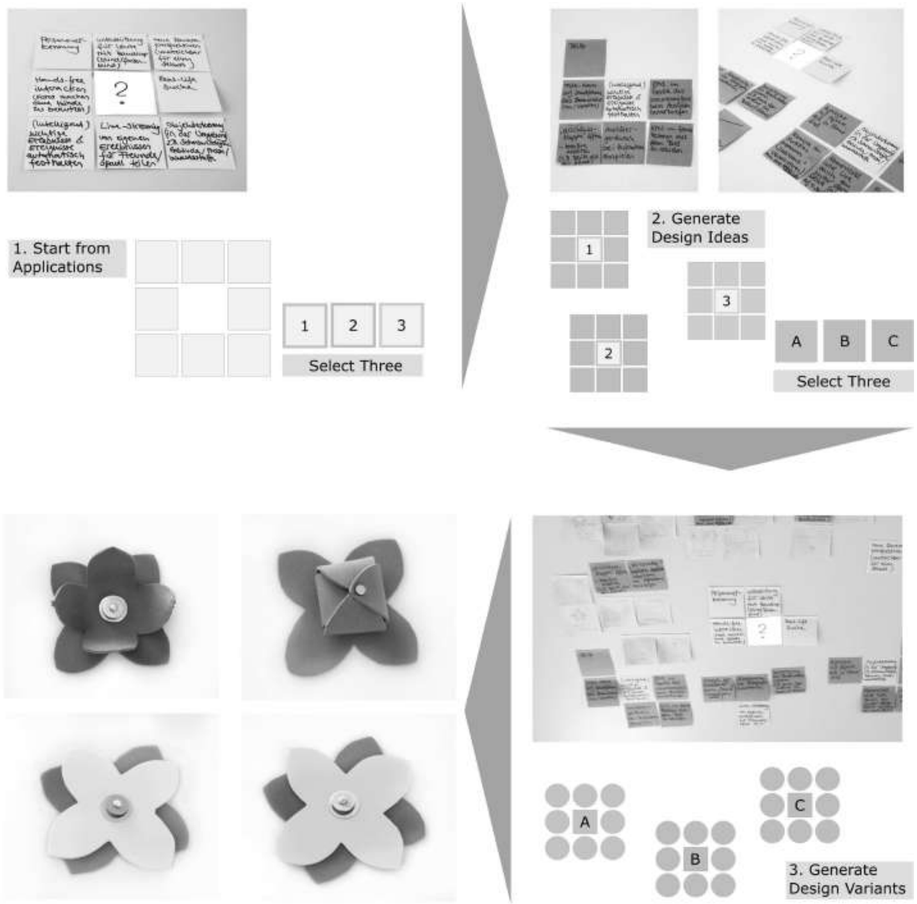


Figure 4.12: The design sessions were organized following the Lotus Flower Method in four steps (each: schematic explanation at the bottom, documentation of the design session at the top). Participants started out from applications that can be enabled with wearable cameras, of which they then selected three (top, left). In two subsequent iterations (top and lower right) they generated design ideas, selected their three favorites and elaborated on those by designing different variants. Finally, one selected idea was visualized as low-fidelity prototype (here: Prototype A, "Status Flower", lower left).

Experiment Design & Participants

Design solutions developed in participatory design can produce solutions relevant to users' existing needs and desires, but may be less effective at producing innovative ideas that answer users' future or latent needs [San01]. In addition, privacy notices are an abstract, non-tangible concept, and body-worn cameras not (yet) widely adopted, which makes it too challenging for non-experts to come up with novel design strategies for privacy notices. Thus, we decided to recruit experts instead of potential users for our experiments.

Working with experts promises not only to involve people that are able to reflect on needs that users are unaware of, experts also know the needs of many users from a survey perspective. Therefore, one expert can bring in the expertise of many users. In consequence, we deemed in-depth design exercises with a limited number of experts more suitable than for the particular design challenge (privacy notices of body-worn cameras) than large scale surveys, and conducted 8 design sessions (2-3h) with 2 expert participants each.

In a successful and complete product design process, iterating through analysis, design, evaluation and redesign phases requires a lot of time [BW10]. In contrast, our experiments aim for incomplete, but interesting design artifacts that each addresses a few perspectives of the complex design challenges described beforehand. There are two reasons for this approach: first, the time frame of a single design session is too short for a fully-developed product. Second, by deliberately aiming for the incomplete and imperfect, we also allow not-fully thought out, not (yet) realizable and exaggerated or visionary ideas to be part of the created artifacts. Thus, the design artifacts' perspectives are extended towards abstract and creative thinking.

Referring to the constructivism paradigm [GL00; Sch$^+$00], which assumes that novel solutions are constructed from the learner's (here: expert's) previous knowledge, we expected the potential perspectives on the design challenges to be diverse. Thus we intentionally recruited experts with different research focuses. Each pair of experts contributes one or multiple perspectives on privacy notices of body-worn cameras from which the underlying design strategies are then reconstructed. To more holistically understand strengths and weaknesses of each design strategy, we use the design artifacts created by experts to stimulate a discourse around our research topic [ZFE07], which, in our case, is the question how the design of body-worn smart cameras can address *justification* and *situation awareness*. This discourse is twofold. First, we detail how the experts themselves reflected on their designs, which happened right after they finished the design process. Second, UX experts analyzed the design artifacts, which we describe in greater detail in the section on *Experiment 2: UX Evaluation*.

We conducted 8 design sessions with 2 experts participating in each session as a design team. They were teamed up, as design is usually done in teams, and discussion often fruitfully enforces creativity [AEF$^+$00]. To generate design artifacts that embed a wide scope of design perspectives, we recruited design research teams from our community that were covering the following expertise: (1) information retrieval (2) wearable computing (3) shape changing interfaces (4) notifications (5) ambient light displays (6) social context technologies (7) integrated media, and (8) cognitive science. They were recruited from different groups at four universities and one research institute. Our 16 experts (8f, 8m, 0d) were between 23 and 43 years (M=30, SD=5).

Procedure & Task

Our design sessions were similarly structured as the design thinking phases [BK09]. Design thinking could, of course, not fully be applied as the temporal limitation of our sessions did not allow for iteration and readdressing previous phases.

First, tackling the phases *empathy* and *design*, we started with a presentation about the state-of-the-art as well as trends and challenges of current Augmented Reality (AR) smart glasses and body-worn cameras. We also gave an overview of related research and clearly articulated our targeted problems of users' justification and bystanders' situation awareness referring to the work of Portnoff et al. [PLE+15]. Summarizing previous work's conclusions, we highlighted that LEDs do neither work for user justification nor for bystanders situation awareness, as they show significant weaknesses regarding *noticeability*, *understandability*, *security*, and *trustworthiness*.

Second, participants were instructed to ideate alternatives in a guided design process, starting from the *ideation* phase. We guided our experts through a 3-step ideation session applying the Lotus Flower Method (see Figure 4.12). The Lotus Flower Method [Mic14] – or Lotus Blossom Technique [Tat90] – is a method for group brainstorming that originated in the 1990s. It is a problem-solving approach where each successive step provides a more in-depth look at potential solutions to the problem. Although highly structured, it fosters imagination and innovative thinking while it is at the same time easy to use and explain [Hig94; Hig96; Smi98]. Balancing structure and flexibility, the Lotus Flower Method was ideal for our research intentions.

All experts were provided with post-its and pens. Then, using a top-down approach, we asked in step 1 *"What applications can be enabled with wearable smart cameras?"* In step 2, each team selected 3 to 4 applications and answered for them the following question: *"How and where could a smart camera communicate to spectators whether they are being captured and what the images are being used for?"*. In step 3, again 3 ideas should be selected and be brought into the next design level through developing different variations of selected ideas. The focus of that task was on *"How could the UI communicate the application kind and how the camera mode?"* For each step, we reminded the design teams to be aware of all kinds of modalities and to avoid status LEDs.

Third, we arranged a *prototype* phase. Here, each expert team chose one of their ideas generated in step 3 of the *ideation* phase. That idea was then prototyped using a material box equipped with all kinds of materials and making tools inspired by IDEO's Tech Box[14].

Figure 4.13: We provided the participants with a prototyping box to foster creativity and to help visualize their ideas. Comprised were making tools and materials including cardboard and paper, foam rubber and felt, wooden blocks and sticks, modeling clay and play dough, and various items to simulate multimodal output, e.g., squeakers, rattle disks, or squeeze boxes.

Forth, we tackled the *test* phase through encouraging our experts to evaluate their prototypes. The experts rated on a 7 item Likert scale *"How well the prototyped idea communicate the camera status?"* as well as *"How well does it communicate the kind of application?"* The ratings were intended to get the experts in the mood of critical reflection on their ideas. Followed by that, we gathered qualitative feedback through asking for specific design elements of their prototypes. In a semi-structured interview, they were asked to name those elements particularly important/beneficial respectively problematic to situation awareness, and those elements particularly important/beneficial respectively problematic for justification. Sessions lasted 2 to 3 hours. Participants were served with sweets and beverages. There was no monetary compensation.

[14] A curated collection of various technologies, materials and mechanisms, source of inspiration when designers are being stuck. C.f., Greenberg et al. [GCM+13], p.58.

Measurements

We recorded the *ideation* phase by photographing the arranged post-its. Results of the *prototype* phase were captured on video and with still images of the prototypes. Ratings and answers of the *test* phase were filled in and saved in Google docs.

4.3.3 Experiment 2: UX Evaluation

Nikander et al. [NLL14] demonstrate that the outcome of concept evaluations tends to be biased, and not objective when designers evaluate a set of designs including their own concepts or ideas. For this reason, we supplement the design team's evaluations of their own prototypes (experiment 1) with a second idea evaluation, where we invited UX and HCI experts that had not taken part in our design session. The major goal of the evaluation was analyzing the meta-concepts underlying the designs from the first session and gather opinions on how well they solve the problems *noticeability*, *understandability*, *security*, and *trustworthiness*. However, as explained above, the generated design artifacts cannot take the place of ready-made product ideas. We understand them as truly subjective, and high-quality perspectives on the research challenges, which – during the design session – became physical artifacts.

Experiment Design & Participants

We conducted expert interviews aiming to capture a meta-perspective on the generated design strategies and how they target our research challenges (again, rather than aiming for finding a real product design). Hence, we interviewed UX as well as HCI experts and asked them to analyze the design artifacts created in the first experiment. We invited 12 HCI and UX experts (6 m / 6 f), aged 25 to 40 ($M = 30, SD = 4$) who had in average 7 years of experience (SD = 4).

Procedure, Task & Measurements

There are no established usability principles (heuristics) or evaluation criteria for body-worn or Augmented Reality smart cameras (yet). Nevertheless, general criteria for privacy notices, such as presented by Cranor et al. [Cra06], Dourish et al. [DGdL$^+$04], and Bellotti and Sellen [BS93] are available and had provided the theoretical groundwork for the design requirements that were given to the experts during the first iteration of design sessions. For this reason, we re-used the design requirements and transferred them into open interview questions.

For each of the 8 design artifacts, we prepared a printed A4 design explanation card containing 3-4 pictures and a descriptive text. A short version of the explanations is shown in Table 4.6. To encourage our interview partners to judge the design artifacts, we asked them for rating each design regarding the pre-defined requirements, e.g. *"How noticeable is the camera's status in the described design?"*. The ratings were measured on a 7 item Likert scale (1: "very poorly" to 7: "very well"). Again, through the provision of a numerical rating, the expert participants should be directed towards re-thinking the concepts and establishing a consolidated opinion, before elaborating. Making a decision about the rating was only used as an "opinion builder" to serve as starting point to reflect on the ideas. Then, in a second step, the participants were asked to explain their rating, which we later used as basis for analysis and discussion. The design artifacts were presented in randomized order. Ratings and interview answers were recorded using Google docs.

4.3.4 Results

This section jointly presents results of the expert design study (Experiment 1) and the UX evaluation (Experiment 2). Each design team visualized their favorite concept from the ideation phase as a low-fidelity prototype. We denote qualitative statements and ideas by the design teams as "DT". An overview of the resulting prototypes is given in Table 4.6. The prototypes represent iteratively developed interaction concepts that are made physically using material and low-fidelity prototyping techniques. As result, we got 8 design artifacts that address the issues previously mentioned with AR and smart cameras. The design artifacts serve as base for identifying design strategies that make AR and smart cams more usable in public.

In addition to the prototypes, we analyzed the ideas of step 2 and 3 of the *ideation* phase (Lotus Flower) using inductive category development, as suggested by Mayring [May14] and extracted design ideas. Then, we compared the developed prototypes among each other and to the extracted ideas, and worked out overarching approaches to create sufficiently noticeable, understandable, secure and trustworthy privacy notices. We subsequently present these overarching approaches as design strategies.

Discovered design strategies were analyzed qualitatively. We carefully selected suitable qualitative comments from our expert evaluation that help reflecting on the design strategies from a meta-perspective. As explained earlier, the expert rating of the prototypes served as "opinion builder" so that the experts have a starting point from where they can explain their opinion about the ideas. Hence, we selectively report ratings that have clear scoring when describing the design strategies to show what concepts were found most or least promising. Here, we present the design strategies and substantiate them through expert ratings as well as through expert comments (denoted as "E") explaining their critical and promising aspects.

Physical Occlusion

A concept that, in contrast to software solutions, was rated trustworthy is the occlusion of the camera lens with opaque material (Prototype A & C) which

	Prototype A DT1	**Prototype B** DT2	**Prototype C** DT3	**Prototype D** DT4
Prototype Depiction				
Short Description	A flower-shaped camera enclosure covers the lens with an opaque material when no recording takes place ("closed bud" metaphor). Different types of recordings (video, still images) are visualized through color changing petals.	The camera device has an embedded printer that displays the captures as physical artifacts. The artifacts also serve as controls that can be used by the bystander to delete the recording or adjust the audience it may be shared to.	A kid's camera shaped as a character with the lens embedded in the eye. Eyelid and ears close when no video/audio is captured ("eyelid" metaphor). The necks tilting angle indicates the angle of vision.	The camera device is projecting a frustum on the floor, indicating what area is being captured. Additionally, icons are projected that indicate the nature of the recording, e.g., video/still images as well as whether (and where) the imagery might be shared.
Design Strategies	physical occlusion color-coding	transfer of control displayed camera image	physical occlusion indicated angle of vision	indicated angle of vision indicate captured area visible device actions text & icon

	Prototype E DT5	**Prototype F** DT6	**Prototype G** DT7	**Prototype H** DT8
Prototype Depiction				
Short Description	The camera device integrates two icons, one for “analysis only” and one for “persistent storage”/“recording” associated with a color (“red” and “blue”) as well as a textual label. The corresponding color is repeated as circling point light on a LED circle surrounding the lens.	The camera device depicts or “mirrors” the camera’s view of the scene when the device is turned on. Its image is shown in an abstract way to visualize object or person detection/recognition (here: 3 persons) and where detected entities are located in the field of view.	The camera device (here: glasses) “mirrors” the camera view on its frame and lenses. If a face is recognized, the frame on the glasses front lights up (for the detected bystander to see) and vibrates (for the user to feel the event).	This smart glasses device for blind people acts as normal (dark) sunglasses when turned off. When turned on it shows the camera image on one side and an icon and textual description of the usage intention on the other side.
Design Strategies	text & icon color-coding visible device actions	displayed camera image visible device actions	displayed camera image visible device actions	text & icon color-coding displayed camera image

Table 4.6: Physical design artifacts created during the design sessions of Experiment 1. Each artifact is presented along with characteristic design strategies obtained from inductive category development and comparative analysis.

is reflected by the highly rated security (Mdn=6, SD=1.8) and trustworthiness (Mdn=5, SD=1.7) of Prototype A. This idea is inspired by traditional camera lens covers (“irises”), which prevents image capturing even if the software would still be in recording state (c.f., Figure 4.14).

The occlusion ideas show that that approach allows for playfulness and physical design of, for example, a flower metaphor with opening and closing leaflets (Prototype A), or a physical “eye lid” metaphor as used in Prototype C. Both serve to reassure bystanders of what a camera can capture and what is impossible to be recorded. This effect can also be leveraged by playing around with other physically limiting attributes of the camera, for example the field-of-view, FOV (through tilting the camera or using glare shields or blenders). The simplicity of that concept was very much appreciated by E10 who stated *“Metaphors ... for everybody. With open eyes, you can see, with closed eyes you can’t. Same with the direction of the eye.”*

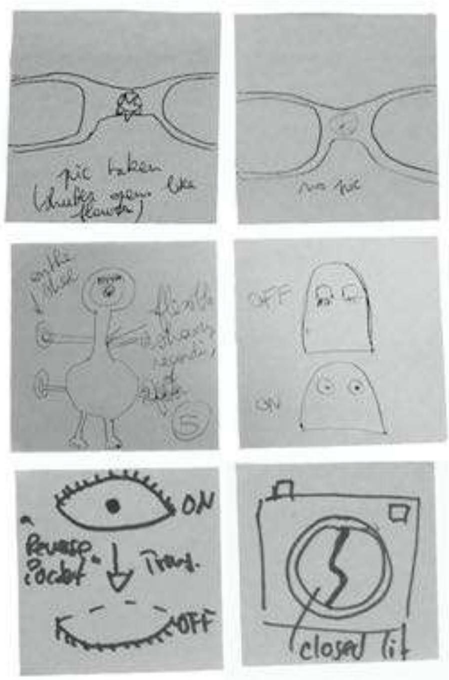


Figure 4.14: Post-it notes from Experiment 1. The design strategy *physical occlusion* was re-occuringly noted during the ideation task and associated with a range of metaphors, including flower petals (top), eyelids (middle and bottom left) and irises (bottom right).

Indicated Capture Area and Angle of Vision

Depicting the camera’s frustum in the environment (Prototype D, see Figure 4.15) leads to high noticeability (Mdn=6, SD=1.6). Variants had been proposed also during the phases of *ideation*, where participants suggested metaphors such as “Aura”, “Shine” or “Halo” to indicate capturing angle and distance or projecting an area on the floor (c.f., Figure 4.15). Consequently, if inside the captured frame, a bystander could step out of it knowing where to stand without being captured.

While this concept can be easily seen (E3) and is a *"good way of giving context to other people"* (E4), the projector could be masked (E4, E5, E6, E8), and therefore, E12 even *"won't trust the projector operation"*.

Figure 4.15: Constrained by characteristics of the lens, a photograph is a 2D projection of the spatial environment. The nature of this projection is also relevant to bystanders who might ask "Am I in the picture?" Prototype D (left: sketched concept, right: low-fidelity artifact) answers by projecting the camera's frustum.

Displayed Camera Image

In their final prototype, four out of eight design teams (DT) suggested to communicate to bystanders what the camera was recording by displaying the camera image (Prototypes B, F, G, H). This strategy follows a "What-you-see-is-what-you-get" approach, as appreciated by E8: *"The device is feeding back what it captures."* In consequence, this strategy becomes very understandable, which is emphasized by the two highest ratings for understandability, the understandable camera status of Prototype H (Mdn=6.5, SD=0.8) as well as of the understandable application purpose of Prototype F and H (F: Mdn=6.5, SD=1.5, H: Mdn=6.5, SD=2.0). Displaying the camera image may be intuitive, as the method is building on what users know about digital cameras. On the other hand, remote display locations (e.g. on the chest) may be a problem as the connection of the camera and the camera image might not always be obvious: *"[The prototype] does not really link image and camera on a first glance"* (DT6). Moreover, even though the camera could be recording, *"The display can still be covered if I just put the camera upside down in my shirt pocket"* (E5 about Prototype F). Another problem of this strategy (as of any but the physical occlusion) is a lack of trustworthiness. Experts mention that the device could be capturing even, despite a software controlled display indicating the opposite: *"If the displayed video was paused, it [the camera] could still capture"* (E2). However, E10 noted that *"an abstraction of the image increases the trustworthiness"*, but E8 raised the concern that it was unclear whether *"the raw image [was] saved somewhere?"*.

Visible Device Actions

While the previously discussed strategy ("displaying the camera image") replicates the captured image, other suggestions aimed to make usage intentions visible to provide a better understanding of what the image will be used for. DT6 suggested, for instance, displaying the result of image processing to both the user and the bystander, through displaying emojis on smart glasses when performing emotion detection to communicate to the bystander which sentiment has been recognized. That would allow to better show what kind of application is used (E1). Further design ideas made use of abstractions (Prototype F, G) to symbolize that objects or persons were detected, e.g., highlighting a "view finder" on successful face recognition. However, this only communicates that something has been recognized but not for what purpose (E11). The proposed solutions have been criticized for a lack of understandability (E8, E9), which could potentially be achieved better using application icons (E2), as explained in the next paragraph.

Color-coding, Text & Icon

The experts proposed established methods to visualize information, especially concepts that require only little display space, were proposed. Colors can be used to symbolize (or "code") different kinds of stati or meanings. Color-coding of some sort has been used in Prototype A, E and H. However, using color codes is easier to implement than other design strategies, experts have doubts about the understandability of such visualization as, for example, *"Blossom color change/flash does not inform us exactly of what is happening"* (E7). Such concern was already stated from the design team itself when reflecting on their prototype: *"We're not sure whether the glowing, blinking, and steady colour is intuitive"* (DT1).

Textual displays, e.g., "recording" have been suggested in Prototypes E and H, which may be easier to get but hard to read from greater distance. Moreover, various icons or pictograms were proposed to illustrate the camera's status and the purpose of recording, persistence of data storage or the targeted platform for sharing (Prototype D). Although, icons are widely-used, they *"can have different meanings if the audience is not trained for it"* (E11), and hence, *"[i]conic design could be unintuitive"* (DT5). Using well-known icons, e.g., associated with applications (E5) or social media (E6, E8), can communicate what application is accessing the image. Nevertheless, there is some vagueness, e.g., where or to whom social media would share an image (E9, E11), which would require a new consent vocabulary of icons (E5).

Transfer of Control

During *ideation*, different mechanisms to transfer control over the image to the bystander, were proposed, e.g., using gesture or voice commands such as "camera off" to disable a third party camera. Prototype B suggests to put the bystander in control and to enable him/her to consent (or object) to being recorded, for example, through deleting the image. Alternatively, (s)he can allow the user to share it via a social network. This idea also embodies the notion of a person's ownership of his/her image. While it is difficult to fully control the distribution of digital media, this is truly possible with analog media. Protoype B encapsulates the control into an analog artifact and hands the picture over to the captured person (see Figure 4.16). While this idea lacks in transparency whether the camera is recording or not (E5, E6, E7), and the feedback about the recording might be given too late to be rejected by the bystander (E8), Prototype 2 presents an interesting and truly novel approach for a transfer of control over the image usage from user to bystander. However, experts also noted a lack of trust regarding both, user and used technology: *"I don't trust human beings, and this is a big factor here"* (E10), *"I cannot verify what has been recorded and if the bubble really was pressed"* (E9), The *"camera could still store images"* (E6). However, it is appreciated by E9 that – after handing over the physical control – the captured person can decide about her/his likeness. In summary, experts liked the principle of handing over control, but criticized how this aim was implemented in the low-fidelity prototype.

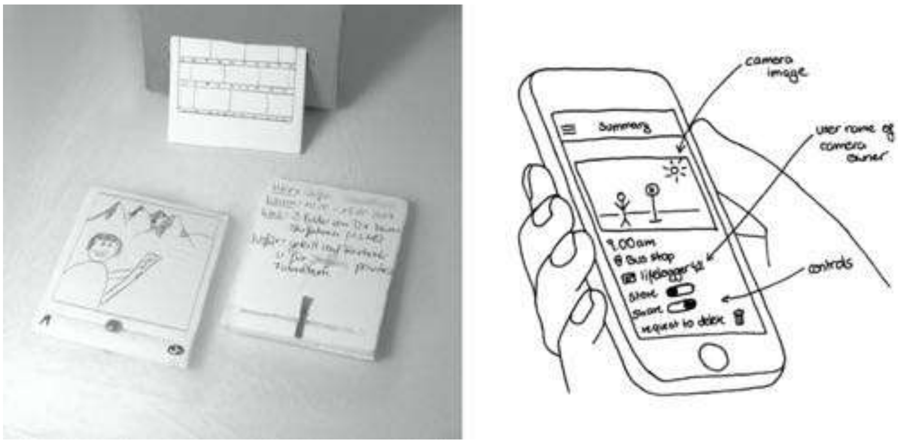


Figure 4.16: While prototype B (left) literally hands over control to the bystander by giving them a control card, the same design strategy, *transfer of control*, might also be realized via a smart phone app (right).

4.3.5 Discussion

To derive design recommendations and to close the loop on the evaluation criteria, noticeability, understandability, security, and trustworthiness, presented in the section on *Problem Description*, we discuss how the identified design strategies address the criteria as well as how they relate to previous work.

Improving Noticeability

Noticeability, i.e., whether user's notice a privacy indicator or not is an important quality criteria [Cra06] of privacy notices. Design strategies that made a device most noticeable were those that display the camera image or the ones indicating the capture area. A reason for the good noticeability of these strategies is surely the visual dominance of the shown content and its well visible placement. In the case of body-worn cameras, its status, e.g, recording, idle, or off, but also the camera's presence and location has to be communicated. The latter fails, if the camera is not recognized as such, as e.g, criticized for Prototype C: *"Having [a] hidden camera is not socially acceptable"* (DT3). On the other hand, privacy notices that merely inform bystanders – e.g., "Warning: CCTV in use" signs or Protoype D's "recording", but do not offer actionable and meaningful choices are not effective [SBD+15].

However, procedures or technologies realizing choice of consent or mediation of privacy preferences (c.f., [MT14; PSH+11]) also need to appropriately notify bystanders of the necessity of choice in the first place. Procedures that ask for consent without prior notice, might satisfy the need for *justification*, but not the need for *situation awareness*. A lack of notice was also criticized by the UX experts: *"It's a Kinder Surprise*[15] *- only when you have been captured you can choose what you do"* (E7 about Prototype B). While the control card (Prototype B) provided the bystander with control over the captured imagery and the option to withdraw his/her consent to recording, this was only after (s)he had already been recorded. Thus, the request for consent was not coupled with an appropriately timed notice: ideally, consent and notice complement each other.

> **Recommendation:** Combine consent and notice in a meaningful way; First notify and make both, user and bystander aware of the situation, then ask for consent.

Improving Understandability

Bystanders of body-worn cameras encounter them incidentally and potentially without preparation. Hence, privacy notices targeted at bystanders need to be understandable without prior knowledge. Egelman et al. [EKC15] note that a lack of familiarity with e.g., face detection and recognition, video recording and visual tracking, makes it difficult to design distinguishable icons presenting those concepts, which is suggested through the design strategy: visible device action. This is problematic, as according to Moyes et al. "an icon [that] is not guessable it is not necessarily an unsuccessful icon" [MJ93]. In consequence, while icons, related techniques (e.g., earcons [BSG89]), and also color codes can be beneficial for primary users that had the opportunity to learn their meaning, they do not achieve the goal of *situation awareness* on the bystanders' side. In addition, they

[15] Popular sweet, a chocolate egg containing a small plastic toy, `https://en.wikipedia.org/wiki/Kinder_Surprise`, accessed 2019

might be inaccessible to users suffering from color blindness. Textual displays can only partially overcome this problem, as the bystander would need to be able to see it under readable conditions (lighting conditions, glare, scale), and understand, both used language and the notices meaning. Metaphors, such as e.g., the “eye lid” (Prototype C), “iris”, or “bud” (Prototype A) might be a promising approach, whose effectiveness will have to be proven by future work. Approaches from cinematography [MW00] could also inspire non-iconic, but simple 2D visualizations of captured regions (c.f., Gustafson et al. [GBG+08]), as outlined by Prototype D.

> **Recommendation:** Privacy notices targeting bystanders, should avoid any element that has to be known (written language), learned (color codes) or cannot be guessed easily (complex, unfamiliar icons), as well as consider accessibility.

Improving Security & Trustworthiness

Concerning privacy notices, security and perceived trustworthiness are closely interconnected. However, an unspoofable, i.e., objectively secure technique, is not necessarily perceived as fully trustworthy. A design strategy that can achieve both is to physically block the camera lens. Evidence about webcam covering behavior [MSL+16] as well as homemade camera covers[16], suggest that this might be an intuitive and higly trustworthy option (also noted by Bellotti et al. [BS93]). In the context of body-worn cameras this strategy could act reassuringly by justifying both needs, *situation awareness* and *justification*. However, noticeability and understandability might largely depend on the visual design of the shutter or switch, particularly whether the camera is still recognizable as such.

Shutters and switches, but also any other enabling/disabling function of body-worn cameras can be operated manually or automatic. Manual operation by the user might be easy to realize, but also prone to human error and dishonesty, as noted during the UX evaluation: *“If you have trustworthy users, the system is trustworthy. Utopia.”* (E10 about Prototype B). For this reason, manually disabling a camera might not be predictable enough from a bystander’s perspective, as they cannot be sure whether the user will actually remember or be willing to disable the camera, when, e.g., entering a public bathroom or swimming pool. Moreover, notifying displays could be deliberately hidden by camera users. Hence, the location of the camera lens and the notifying display should be at the same position, which ensures that of the display is occluded that lens is occluded as well.

Due to the mistrust in users as outlined above, automatic, software-controlled solutions, e.g., based on sensors[17] that ensure bystander privacy might be preferable.

[16] Biehler, Glass Privacy Cover, `https://www.thingiverse.com/thing:182763`, accessed 2019
[17] Patent for a computing device camera view controller and shutter, `https://www.google.com/patents/WO2016090351A1`, accessed 2019

This is a challenge for future research, as they would require sensing procedures that, unlike e.g., microphones, do not infringe with the users privacy and that are robust enough to reliably react to changes regarding the privacy sensitivity of a situation.

> **Recommendation:** Privacy notices should provide bystanders with a reassuring mechanism to rule out false positives (recording without indication), and automatically react to privacy sensitive situations in a predictable and reliable way.

Limitations

For our experiments, we explicitly recruited UX / HCI experts. Thus, actual users did not participate in the design of the prototypes. For this reason, their views might have been omitted in this work. However, as aforementioned starting out from expert perspectives potentially creates more novel and visionary ideas. Nevertheless, the desirability, and acceptability of those ideas will have to be evaluated with actual users (and potential bystanders) on a larger-scale. We attend to this in Chapters 5.2, 6.1 and 6.2. With their relatively small scale our studies do not provide a generalizable cross section of opinions. However, we believe that, as stated by Nielsen [Nie92], specialists can act as "double experts" with their expertise covering the kind of interface being evaluated, as well as its users, thus providing a survey perspective. Nevertheless, particularly creative or extraordinary solutions might have been missed. On the provision of their informed consent for experiment one, participants were informed that they will be asked to prototype in the end. Thus, they might have been biased towards rejecting concepts that are hard to build, e.g., the "odor emitting camera" (DT6).

4.3.6 Summary

LED status lights are an established option to signal whether a wearable camera is recording, but lack *noticeability*, *understandability*, *security* and *trustworthiness*. In this work, we investigated alternative announcement mechanisms in the context of body-worn cameras addressing those problems. From a UX analysis of design strategies based on 8 physical artifacts designed by experts, we derive design recommendations for privacy notices and privacy mediating technologies for body-worn cameras. Providing potential starting points for product design, our recommendations address a timely issue, as the increasing dissemination of wearable consumer cameras and the projected EU legislation (GDPR, [Reg16]) demand effective solutions for privacy notices, that realize privacy-by-design and that are acceptable from the perspectives of all stakeholders, including users, bystanders and manufacturers.

4.4 Summary and Conclusion

In this chapter we went through HCD's *Ideate & Design* phase. From the preceding phase, *Observe & Understand*, we had identified *privacy concerns* as crucial factor causing a lack of social acceptability of body-worn cameras. We furthermore extrapolated justification, situation awareness and the option to object as essential user and bystander needs. We addressed these needs through exploring privacy-mediating procedures for body-worn cameras. We contributed a tool for facilitating participatory design, the Privacy Mediation Cards, and insights about expectations towards body-worn cameras in public spaces. We elaborated on concrete compilations of design options originating from participatory-design sessions (N=26). From our participatory design sessions, we furthermore identified two design challenges, namely the provision of unadorned preparation-free bystander controls, and the design of suitable status indicators for body-worn cameras. We address these challenges by contributing insights about suitability (ambiguity, understandability, representativeness, social acceptability, comfort and ethicality) of gestural commands for Opt-in and Opt-out controls. Moreover, we contribute 3 design recommendations of status indicators for body-worn cameras: (1) meaningful combination of notice and consent, (2) avoidance of elements that have to be known or learned, and (3) provision of proactive, contextual and reassuring mechanisms.

4.4.1 Generalizability

While some of the findings and experiences reported in this chapter might transfer well beyond the application area of body-worn cameras, others might not. Thus, this section discusses their generalizability and points out to which scope they are applicable.

The Privacy Mediation Cards, introduced in Section 4.1 themselves are highly targeted and focused on camera technologies. Although their applicability is not limited to RGB cameras, and might, for instance, also include RGBD, near- or far-IR, and structured light approaches, they are most likely not suited to design for social acceptability in other controversial areas, e.g. voice user interfaces, or smart implants. The underlying concept, i.e., the provision of a mutual basis of (technical) knowledge, might however be applied to these areas. We are confident that this knowledge-based, and solution-oriented approach can be beneficial for participatory design, particularly to increase citizens' involvement in the context of not sufficiently socially acceptable or controversial technologies. By reporting on design considerations and process, and contextualizing our work with similar approaches [MGV+14], we contribute a starting point for technologies not covered by our card deck.

In Section 4.2 we report on a guessability-style elicitation study, and an online (crowdsourcing) survey, an established approach in researching gestures and social acceptability (c.f., Section 2.2). Due to the latter studies' relatively large sample size (N=127), and quota-sampling from Europe and North America (50% each), the results likely generalize for western cultures. The results are also transferable to other types of technologies (e.g., audio), except for where "image taking" or "camera" metaphors are used, as these metaphors are too tightly associated with camera technology. While the approach succeeded in determining and verifying a promising set of Opt-in and Opt-out gestures, it also exposed the procedure's potential weaknesses: focusing on specific interaction techniques (here: gestures), e.g., in terms of (relative) social acceptability, can cause a lack of awareness for their applicability in (social) context: is it ethical to require bystanders to opt-out? Thus, we believe it is essential to complement these (focused) methods qualitatively: in the presented studies, reservations with regard to the practicality of Opt-in/Opt-out, and the ethicality of Opt-out were not present in the elicitation study, and only surfaced from the crowdsourcing studies' qualitative analysis. We believe this "heads-up", to be essential in context of the current practices of researching social acceptability (c.f., Section 2.2) and to generalize widely.

Although we focused our recommendations resulting from the (co-)design activities presented in Section 4.3 on body-worn cameras, we believe that they essentially generalize beyond camera devices. Specifically, the need for a meaningful combination of notice and consent, i.e., obtaining permission before data collection (*"Kinder Surprise"* comparison), is crucial for many post-WIMP interfaces or applications including continuous sensing (e.g., Amazon Alexa, Google Home).

We further believe that elements that have to be known, learned and cannot be guessed easily should be avoided in all interfaces targeting “walk up and interact” scenarios, or situations where bystanders are involved. Similarly, the needs for proactive privacy protection, and reassuring mechanisms also hold for other types of sensing. However, with some, e.g., voice sensing devices, implementing reassurance can be more challenging: in contrast to camera lenses, physically occluding a microphone has an intensifying instead of reassuring effect on privacy concern.

4.4.2 Implications

The work we presented in this chapter illustrates that in the context of a wearable’s social acceptability it is beneficial to consider device appearance and (visible) device behavior, as well as interaction techniques jointly, as all three can be means of communication with bystanders. Current body-worn camera devices do not make sufficient use of these means of communication: they use LEDs or do not have status indicators at all to provide bystanders with notice. They commonly do not provide controls to bystanders except for the option to verbally address the device user. Considered an essential part of privacy mediation (see Section 4.1), both notice and control are interdependent (see Section 4.3), and may increase social acceptability. In-line with our results, existing “privacy-by-default”, and “privacy-by-design” guidelines and recommendations [Reg16; OD13; Lan01; Cav09], we thus aim for body-worn camera devices that proactively and automatically react to (potentially sensitive) contexts, and provide adaptive, manual controls (including but not limited to gestures) as well as reassuring mechanisms. This aim poses a challenge in terms of implementation, as proactivity through (visual) context detection and reassurance through physically occluding the camera lens are (seemingly) mutually exclusive. We address this contradiction through *Protoyping* (Chapter 5).

5 Prototyping Smart Body-worn Cameras

Prototypes and prototyping play a significant role in HCI. Prototypes, which can be broadly defined as *"any representation of a design idea, regardless of medium"* [HH97], provide a communicable form of ideas and concepts. In fact, "prototype" can refer to a wide range of design representations, from sketches, shape prototypes and enactments, over virtual models and video prototypes, to concrete implementations (almost) resembling a market-ready product. In human-centered design, prototypes serve to iteratively inform and shape design process and design decisions: one idea evolves through the creation of different design representations that may vary in detailedness, so-called "fidelity" or scope. Surprisingly, as evident from the analysis of prior work presented in Section 2.2, *iterative* prototyping is only sparsely applied to design for social acceptability. In consequence, ideas from design activities or recommendations based on empirical studies struggle to proliferate to a system or product.

In this chapter we explore how different prototypes can manifest design ideas for socially acceptable body-worn cameras. We consider two perspectives: first, we detail on different prototyping techniques that make use of shape and visible behavior to candidly inform bystanders about device presence and actions (Section 5.1). Organizing a series of prototyping efforts into an annotated portfolio, we reflect on the iterative prototyping process, the employed metaphors and materials, and potential implications for user studies. We discuss the created prototypes in light of fidelity, realism, wearability and functionality. Second, we evolve one concrete prototype into a fully-functional proof-of-concept system: PrivacEye, eye tracking-enabled, privacy-sensitive smart glasses (Section 5.2). PrivacEye physically occludes the camera lens when the user finds themselves in a potentially privacy-sensitive situation. To re-activate the camera, and to determine when to remove the physical shutter, it utilizes the user's eye movements as indicator for activity and situation. This way, PrivacEye extends the line of research on status indicators presented in Section 4.3, and *implements proactivity and reassurance.*

From a methodical perspective, this chapter exemplifies challenges in advancing ideas from empirical observations over design proposals into concrete implementations of research prototypes. It implements HCD's *Prototype* phase. We note that prototypes are also employed in other HCD phases, e.g., to act as as filters for exploring design options during *Ideate & Design*, or as research vehicles to understand everyday usage during in *Test & Evaluate*. We explicitly focus this chapter on aspects of implementation and look-and-feel [HH97], which we discuss in light of social acceptability.

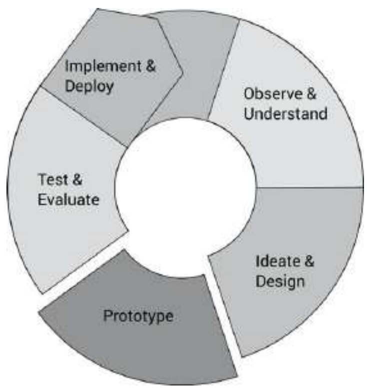


Figure 5.1: Human-centered Design Process. This chapter implements the *Prototype* phase.

5.1 Creating Candid Cameras using Shape and Visible Behavior

Candid interactions are *"techniques for providing awareness about our mobile and wearable device usage to others in the vicinity"* [EGA+15]. Based on our previous findings (outlined as *Observe & Understand* and *Ideate & Design*) and following Ens et al. [EGA+15], we postulate that the social acceptability of body-worn cameras can be improved by emulating candid interactions; i.e., we prototype candid cameras that communicate their status or usage purpose to bystanders using shape and visible behavior. We present and discuss our prototyping efforts taking the form of an annotated portfolio.

5.1.1 Contributions and Related Work

In HCI prototypes are essential. Significant efforts are spent on the development of new prototyping techniques and methods [MKB13; AUK+15]; User studies on novel interactions require researchers to build sophisticated custom prototypes (c.f., the self-build smart watch by Kerber et al. [KKL+17]); Implications for empirical evaluations of different prototype qualities [HM10; TRH+12] and techniques [LPP+06; VMS+19] are widely investigated and debated [JSG+07]. With this in mind, we elaborate on prototyping candid wearable cameras and contribute an annotated portfolio and critical reflection of our prototyping efforts. This section is intentionally designed for breadth instead of depth: providing an overview of different prototyping techniques and methods, from physical to digital, and from low-fidelity to mixed fidelity approaches, it visually describes the journey from empirical finding, "intention of use matters" (Section 3.1), over idea sampling and generation to implementation. Thus, it illustrates the link between empirical findings and artifact creation that is often missing in research on social acceptability in HCI (c.f., Section 2.2). We further intend this section as a starting point and visual inspiration for future work on socially acceptable body-worn cameras.

There is a small amount of closely related work on customizable camera prototypes. Odamaki and Nayar's *CamBits* are self-identifying 3D-printed blocks that can be (re-)configured to shape a variety of different camera devices [ON17]. A string of research by Gaver, Boucher and colleagues focuses on DIY cameras for various research purposes. Their *TaskCam* [BBO+18] and *VisionCam* [BBG+19] serve as tools for cultural probe studies. Both, *TaskCam* and *VisionCam*, come in customizable paper or 3D-printed cases, and with available board layouts and software[1]. The *VisionCam* possesses some candid elements: it features an integrated screen displaying a simplified line drawing of the frame, and its camera lens is physically occluded, swiveling the lens cap activates the camera. In contrast to our work, both camera devices are intended for manual, hand-held usage and not designed for proactive device behavior. Furthermore, Gaver et al. present *My*

[1] Probe Tools project, `https://probetools.net/`, accessed 2019

Naturewatch Camera [GBV+19], a DIY toolkit for leisurely animal observation. It is the only proactive, and context-sensitive camera device in this line of research: positioned outdoors, and in view of bait (e.g, birdseed), it automatically triggers photographs based on captured movement and reacting to RFID bird rings[2]. It is however, not designed for a (human) audience, or does possess any candid properties. Similar to the aforementioned work, the potential social impact of the camera's design was not in focus of the conducted research. In contrast, Cheng et al. [CFT+19] present the *Peekaboo Cam*, a camera-based observational artifact for home ethnography that is shaped like a birdhouse and playfully employs candid behavior. Their work shares a number of key characteristics with ours: a physical lens cover provides privacy and reassurance, a "ding dong" sound and a colored flag notify or inquiry about picture taking, and a push button provides the inhabitants with control over the camera device. On the other hand, the *Peekaboo Cam* is environment-placed, and intended for research purposes, which creates different social dynamics than a personal, wearable camera, e.g., in terms of audience or justification.

Presenting open source research tools or ready-made design artifacts, none of the above prior works focus on *prototyping as a process*. In contrast, we focus this section on the prototyping process, specifically, on choices of materials and techniques. Our contributions are twofold: first, as a detailed case study of prototyping efforts the presented portfolio may be valuable to those interested in design processes and prototyping methods. Second, we exemplify how questions of social acceptability can drive a design process, from idea sampling to implementation, and condense in concrete prototypes.

5.1.2 Annotated Portfolio

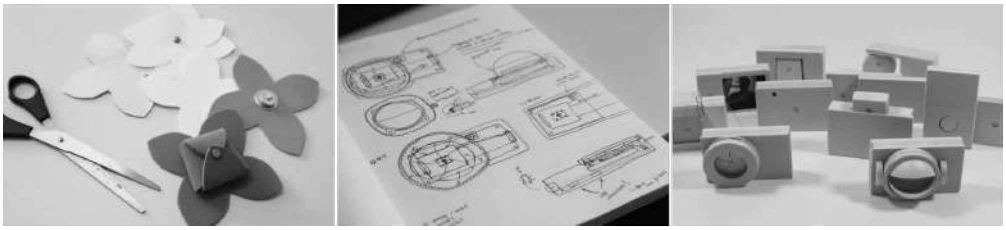
Research prototypes, being conceptually rich artifacts, can benefit from the combination of textual accounts and visuals, e.g., photographs: *"[a]rtifacts are illuminated by annotations. Annotations are illustrated by artifacts"* [GB12]. The combination of visuals and brief textual descriptions ("annotations") allows to highlight design features, capture contrasts and similarities between designs, suggest directions for future work, and make them topical for discussion [Bow12; GB12; JCB12]. Textual annotations can point to details or features present in the illustrating visuals, and establish connections to other aspects not explicitly depicted. This value of more visual research accounts is recognized in paper formats such as photo essays e.g., by Jarvis [JCB12], or pictorials, which are curated in dedicated tracks at DIS[3] and TEI[4]. In addition to being illustrative, annotated portfolios serve to unite multiple individual prototypes (e.g., [HOW+18])

[2] My Naturewatch Camera, `https://mynaturewatch.net`, accessed 2019
[3] DIS 2019 pictorials track, `https://dis2019.com/pictorials/`, accessed 2019
[4] TEI 2020 pictorials track, `https://tei.acm.org/2020/participate/pictorials/`, accessed 2019

or different iterations of one prototype (e.g., [SWO18]) systematically into one holistic body of work. Gaver at al. put this summative nature as *"a single design occupies a point in design space, a collection of designs by the same or associated designers – a portfolio – establishes an area in that space"* [GB12].

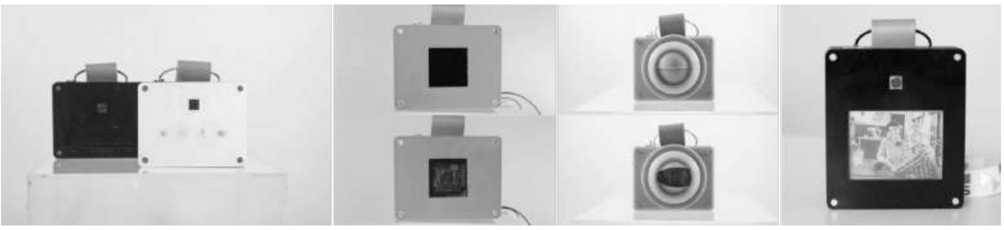
In this section, we bring these two qualities, visual presentation, and holistic examination of multiple prototypes together. We organize various prototypes and research probes into a photo essay creating an annotated portfolio of candid camera prototypes, and prototyping techniques for smart body-worn cameras. With the Portfolio Figures 1 to 12 we provide an informed basis for a critical reflection and discussion of the involved prototyping efforts.

Making Use of Shape and Observable Behavior



Portfolio Figure 1: To explore the notion of cameras communicating themselves to bystanders, we started out from concept ideas of prior work [KWB18], and quick-and-dirty prototypes (left). We produced sketchwork (middle) and blue foam prototypes (right) to explore options of creating cameras that inform bystanders about their actions through shape change (e.g., opening and closing movements, retractable elements) and visible indicators (e.g., opacity or color change).

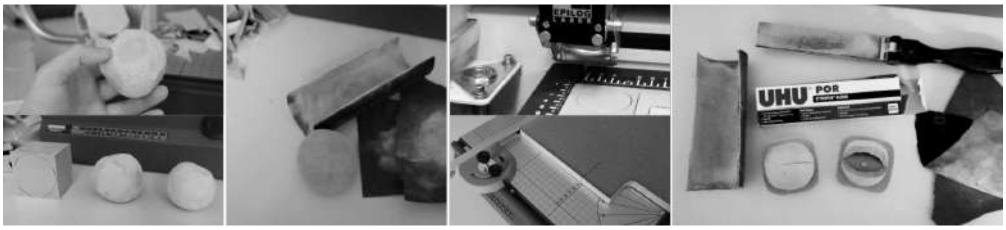
Portfolio Figure 2: Inspired by [GCM+13], we maintained a collection of images, clippings, and sketches for idea sampling (left). These "samples" included research and artwork, consumer products, and notions from fiction or popular culture. Throughout our prototyping efforts some of these samples evolved into functional hardware prototypes (right). Metaphors or key motives (here: anthropomorphism, and positioning on the shoulder, as explored in [Web19]), often arose from the idea samples before being transformed and integrated into prototypes.



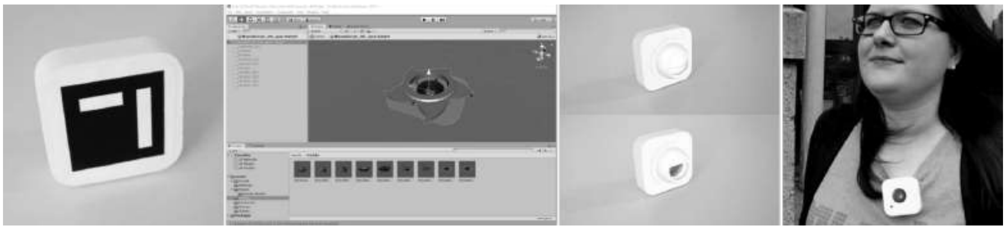
Portfolio Figure 3: After ideation, we implemented a range of different candid behaviors in fully functional, wearable camera devices, including audio, and icons (left), lens occlusion through opacity change using a liquid crystal light valve (black/opaque - transparent) and as "eye metaphor" (middle), and display integration (right). While we did not follow up audio or icons, the display prototype, later called MirrorCam, evolved into research vehicles used in a field study, c.f., Section 6.1.

Smart and Wearable: Exploring Prototype Fidelity

Portfolio Figure 4: The prototypes created throughout our work possessed different characteristics, most significantly they varied in terms of their fidelity. Despite different levels of functionality or look-and-feel, some also shared common characteristics, such as interface metaphors (here: open/closed eye). Except for the right most prototype, the depicted ones also share the same physical format which is based on a state-of-the art device, Google Clips, c.f., [Lov18].

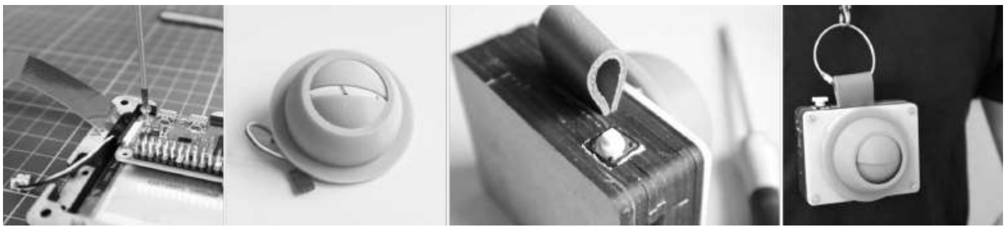


Portfolio Figure 5: Prototyping using Styrofoam ("blue foam"), a popular technique in product design, allows to rapidly create rough to detailed shape prototypes. Styrofoam can be shaped using rasps, files, and sand paper (left), trimmed using a hot wire or laser cutter (middle), and glued. This form of shape prototyping allowed us to experiment with sizes, shapes and metaphors, and to explore the visibility of elements during early prototyping stages, but sets limits to interactivity.



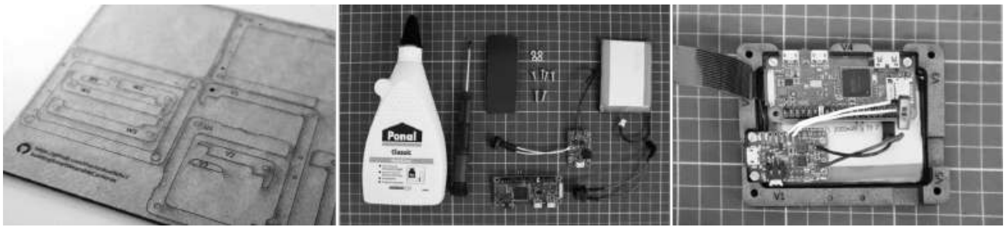
Portfolio Figure 6: Using Augmented Reality (AR) we created (video) prototypes that have a stronger resemblance to consumer devices. We utilized a 3D-printed, camera body, with a marker (flock print) instead of the lens (left). In Unity[5], we created a virtual scene that loaded a video of the camera body, and overlaid the marker with a virtual model, e.g., an iris (middle left), "eye" metaphor (middle right: opened, and closed), or that added a camera lens and LED (right).

Portfolio Figure 7: Integrating custom mechanical components in form factors of the size of consumer devices is challenging. As a workaround we salvaged the iris mechanism of a discarded analogue camera, and mounted it to a 3D-printed case (left). A servo motor opens and closes the mechanical iris. As the case only fits the servo and camera lens, all other electronics, including a Raspberry Pi, and an Arduino were sewn onto a scarf (middle) or worn hidden under it (right).

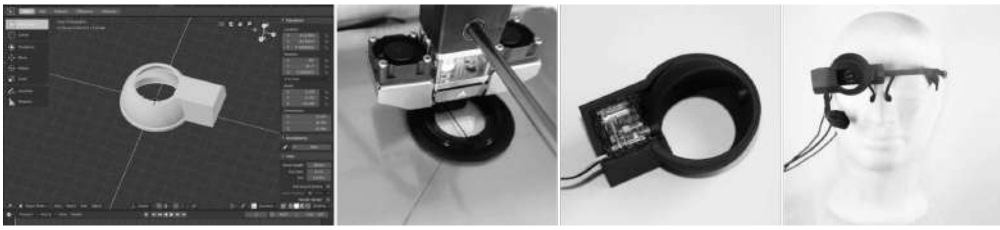


Portfolio Figure 8: To create fully functional hardware prototypes, we made use of small single-board computers (here: Raspberry Pi Zero) that enable basic image processing routines in real time. This allowed the camera to be face-responsive (c.f., Darrell et al. [DTB+02]), and react, e.g., by closing the camera's "eye", to bystander presence or conversations [MSK+18]. Cases were constructed from plywood, acrylic glass, and 3D printed parts, which creates a mixed fidelity, and "prototypical" look-and-feel.

[5]Unity, 3D Development Platform, `https://unity.com/`, accessed 2019

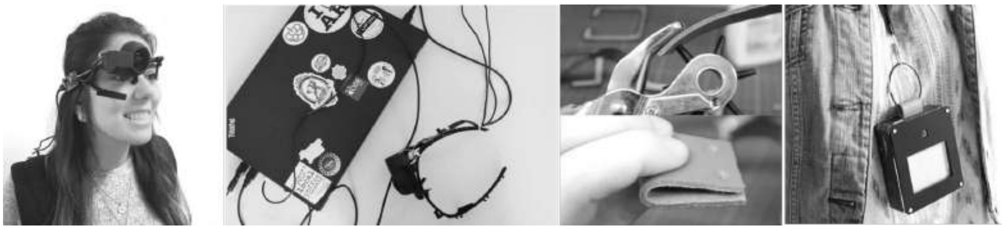


Portfolio Figure 9: We manufactured the cases from laser cuts (left) using a sandwich layering technique; a flexible approach, which is well customizable, and allows for exploration of additional functions, indicators, or use cases. The current design, which we provide on Github[6], fits a Raspberry Pi Zero, charger and power supply, and one push button for simple interactivity. It can be enhanced with candid indicators (Portfolio Figure 3), e.g., the “eye” metaphor design.



Portfolio Figure 10: An additional option for creating candid cameras is to augment existing devices with additional elements. For the PrivacEye prototype we equipped a Pupil eye tracker with an additional mechanical shutter (c.f., Section 5.2). The shutter was 3D-modeled in Blender (left) to fit the shape and exact size of the eye tracking device. After 3D-printing it was fitted with a servo motor (middle), and mounted to the eye tracker with mouldable glue (right).

Towards Field Studies



Portfolio Figure 11: Robustness is essential for field studies, where the device is worn for an extended time period, and during various everyday activities. While the PrivacEye prototype (left, see Section 5.2) required to carry the computational unit, a notebook, in a backpack, the MirrorCam prototype (left, c.f., Section 6.1) fit all electronics in one case. We equipped the chest-worn prototype with a screwed-in leather noose (middle right) that allowed to safely wear it on a lanyard.

[6] `https://github.com/marionkoellehci/buildingSmartWearableCameras`, accessed 2019

Portfolio Figure 12: For our field study (Section 6.1), we prepared study materials (left) to accompany the prototype: information material, questionnaires and diaries to document the experience, and provided the participants with charging devices. We also went through the development of multiple identical prototypes (right) to be able to accommodate multiple participants at the same time.

5.1.3 Discussion

In the following, we reflect on the presented annotated portfolio. We focus our discussion on why and to what extend the presented prototypes are suitable research vehicles.

Fidelity and Realism

A prototype's fidelity, i.e., its detailedness, and resemblance to a finished product largely affects how it is perceived. Our annotated portfolio included a range of low- and mixed fidelity prototypes. Low-fidelity prototypes, which are typically non-functional such as our shape prototypes from blue foam (Portfolio Figure 5), or interfaces made from household or office supplies, paper and cardboard [KWB18], are a useful tool to simulate an actual system. The use of tangible tools facilitates reflection, and helps to illustrate assumptions and concepts [Fri06]. On the other hand, our mixed-fidelity prototypes illustrate the crux of prototyping socially acceptable interfaces: "getting real" in prototypes (c.f., Jones et al. [JSG+07]) is challenging. While our portfolio illustrated two approaches, namely Augmented Reality prototyping (Portfolio Figure 6), and unobtrusively sewn-in electronics (Portfolio Figure 7) that allow to get close to the size of state-of-the art consumer devices, their look-and-feel remains prototypical. Similarly, the augmentation of existing devices, as outlined in Portfolio Figure 10, or as presented by Cobus et al. [CBH19], causes the consumer device to appear "manipulated"; An aspect to keep in mind when evaluating their social acceptability, as it might potentially affect perceived trust.

Wearability and Functionality

There are several definitions of what is "wearable" [GKS+98; GC14b; KWL+11]. While all of the above prototypes are mobile and "body-worn", e.g., carried on the chest using a lanyard, or as a combination of smart glasses and backpack (Portfolio Figure 11), they might not be considered "wearable" in a strict sense.

In their seminal work, Gemperle et al. [GKS+98] provide a thorough discussion of "wearability" along with a set of guidelines. Most notably, they argue against *"single point fastening systems such as clips or shoulder straps"* and for a more dynamic way of enveloping the user's body. Making use of the form factors of existing (non-candid) camera devices, most of the presented prototypes use this kind of fastening techniques (see also Section 1.1). We deliberately made this choice in order to be able to evaluate the employed candid strategies and metaphors against the backdrop of existing devices, and with a specific focus on the social acceptability of these design strategies (see Chapter 6). We note however, that innovative wearable form-factors should be kept in mind for future work. Here, we understand our portfolio as starting point, not as delimiter of the design space.

Requirements and Aesthetics

Our selection of prototypes illustrates a need for trade-offs as also noted previously by Gemperle et al. [GKS+98]: technical requirements have to be weighted against ergonomic and aesthetic ones (c.f., Knight et al. [KSP+05]); Functionality, e.g., available computational intelligence or features, and battery life need to be balanced against device size. As we understand the research prototypes in our portfolio as communicable and testable forms of concepts and ideas (not as products), the "right" balance strongly depends on the intended way of evaluating them. A field study (such as the one presented in Section 6.1) might require a robust and fully functional prototype, with sufficient battery life. In contrast, a design study might benefit from utilizing low-fidelity prototypes, e.g., shape or quick-and-dirty prototypes, or sketches (c.f., Portfolio Figure 1). We believe that it is in fact the combination of a multitude of different prototyping approaches that is most beneficial for knowledge gain; even more so, as the effects of prototype properties (e.g., aesthetics or fidelity) on measures of social acceptability are yet not fully understood – a gap that will have to be filled by future work.

5.1.4 Summary

In this section, we presented a range of different prototyping techniques for smart wearable cameras in the form of a photo essay. Discussing them as annotated portfolio, we do into detail on their fidelity, realism, wearability, functionality, as well as technological and non-technological requirements and aesthetics. The prototypes we presented range from extremely low fidelity to mixed-fidelity prototypes that are fully functional but do not (yet) possess the aesthetics of consumer devices. Through reflection and comparison of a range of prototyping efforts we demonstrated strengths and weaknesses of different techniques. We believe that human-centered design of socially acceptable devices can draw strength from combining these complementary techniques as illustrated by the presented annotated portfolio.

5.2 Utilizing Eye Tracking for Privacy-preserving Behavior

Without question, the use of a mechanical shutter to physically occlude a camera's lens is compelling. Recognized for increasing safety and trustworthiness this simple approach has been noted at multiple locations within this thesis, as well as by prior work [BBG+19; CFT+19; JP14; MSL+16]. Figure 5.10 illustrates an exemplary scenario: the camera shutter closes when the user starts a conversation (mid left) and re-opens when they bid farewell (right). Yet, automatic camera re-activation is challenging, as the closed camera shutter naturally prevents access to scene imagery. We deem options such as manual re-activation, and timed intervals as not satisfactory due to user comfort and trust in the system. Other environment sensing techniques, e.g., far-infrared, FIR [JP14], radar or audio, are also not beneficial as they increase potential issues with bystander privacy. For these reasons we aim for an innovative solution, that allows to de- and re-activate a physical shutter without requiring manual control, and compromising bystander privacy. In this section, we present a proof-of-concept solution, that realizes *proactive, privacy-preserving behavior using eye tracking.*

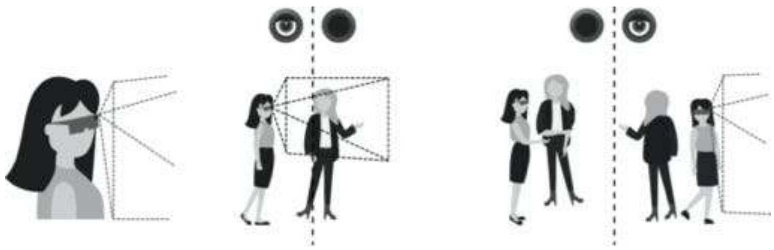


Figure 5.10: Physical shutters are a compelling option to protect privacy. Yet, with the camera shutter closed, visual scene knowledge is not available. As a solution, we propose to infer the right moment for camera re-activation from the user's eye movements.

5.2.1 Contributions and Related Work

Eyewear devices, such as head-mounted displays or augmented reality glasses, have recently emerged as a new research platform in fields such as human-computer interaction, computer vision, or the behavioural and social sciences [BK16]. As part of these devices, a combination of front-facing cameras and camera-based eye tracking sees widespread application: the eye camera records a close-up video of the eye and a high-resolution first-person (scene) camera maps gaze estimates to the real-world scene [KPB14]. Unsurprisingly, as any (front-facing) body-worn camera, the scene camera poses a serious privacy risk. It may not only impair bystander privacy, but also record sensitive personal information, such as login credentials, banking information, or text messages [PZG17]. Related privacy concerns have been found to be affected by context, situation, usage intentions [KKM15], user

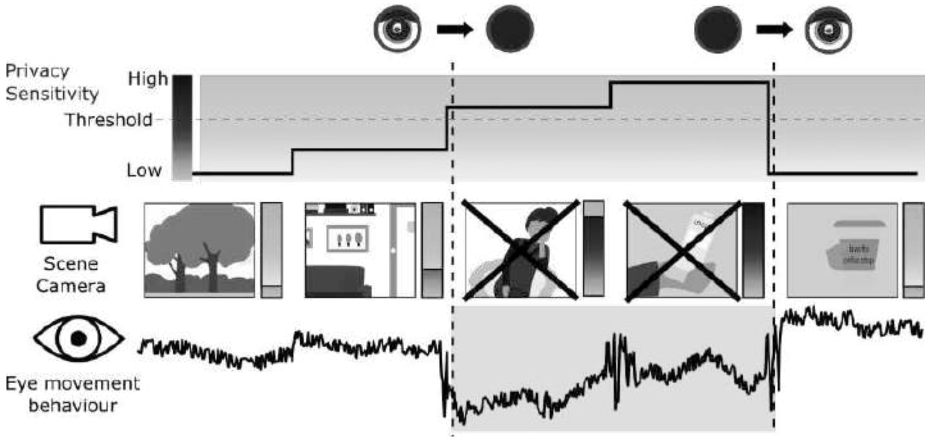


Figure 5.11: Our method uses a mechanical camera shutter (top) to preserve users' and bystanders' privacy with head-mounted eye trackers. Privacy-sensitive situations are detected by combining deep scene image and eye movement features (middle) while changes in eye movement behavior alone trigger the reopening of the camera shutter (bottom).

group [PAF+16], number of people in a picture, and presence of specific objects (e.g., computer displays, ATM cards, physical documents) as discussed by Hoyle at al. [HTA+14]. Consistent with our previous findings (see Chapter 3 and 4), Hoyle et al. highlighted the need for automatic privacy-preserving mechanisms to detect those elements, as individual sharing decisions are likely to be context-dependent and subjective [HTA+14; CFJ16].

In the context of bystander privacy, eye movement analysis is also appealing because it is user-centric, i.e., it only provides information about the user and does not impair bystander privacy. Moreover, eye movements are a rich source of information on a user's everyday activities [BWG+11; SB15a], social interactions and current environment [BWG13], or even a user's personality traits [HLM+18]. As discussed earlier, prior work showed that perceived privacy sensitivity is related to a user's location and activity [HIC+15]. We therefore hypothesize that *privacy sensitivity* which depends on activity and environment, transitively informs a user's *eye movements*. We are the first to confirm this transitivity, which results as a reasoned deduction from the aforementioned prior work.

Based upon this transitivity, we propose PrivacEye, the first prototype of eye tracking-enabled, privacy-sensitive smart glasses with a method for proactive camera de- and re-activation (see Figure 5.11). The key idea and core novelty of our method is to detect users' transitions into and out of privacy-sensitive everyday situations by leveraging both cameras available on state-of-the-art eye trackers. If a privacy-sensitive situation is detected, the scene camera is occluded by a physical shutter. Our design choice to use a non-spoofable physical shutter, which closes for some time and therefore provides feedback to bystanders, is substantiated by

Koelle et al., who highlight an increased trustworthiness over LED lights on the camera or pure software solutions [KWB18]. While this approach is secure and visible to bystanders, it prohibits visual input from the scene. Thus, our method analyses changes in the users' eye movement behaviour alone to detect if they exit a privacy-sensitive situation and then reopens the camera shutter. A naive, vision-only system could reopen the shutter at regular intervals, e.g. every 30 seconds, to detect whether the current situation is still privacy-sensitive. However, this approach may negatively affect perceived reliability and increase mistrust in the system. Thus, our eye-tracking approach promises significant advantages over a purely interval-based approach in terms of user experience and perceived trustworthiness.

Related Work

Research on eye tracking privacy is sparse, and has just recently been taking up more in-depth, specifically with regard to differential privacy [LXD+19; SHH+19]. Thus, our work mostly relates to previous works on privacy concerns with first-person cameras which have been covered earlier in this thesis (Chapters 3 and 4), and privacy enhancing methods for (wearable) cameras, which we discuss subsequently.

To increase the privacy of first-person cameras for bystanders, researchers have suggested communicating their privacy preferences to nearby capture devices using wireless connections as well as mobile or wearable interfaces [KDS+15]. Others have suggested preventing unauthorised recordings by compromising the recorded imagery, e.g., using infra-red light signals [Har10; YGE13] or disturbing face recognition [Har12]. In contrast to our approach, these techniques all require the bystander to take action, which can be impractical due to costs and efforts as noted by Denning et al. [DDK14], and confirmed by our prior work (Sections 4.1, 4.2).

A potential remedy are automatic, or semi-automatic approaches, such as *PlaceAvoider*, a technique that allows users to "blacklist" sensitive spaces, e.g., bedroom or bathroom [TKC+14]. Similarly, *ScreenAvoider* allowed users to control the disclosure of images of computer screens showing potentially private content [KTC+16]. Erickson et al. [ECS14] proposed a method to identify security risks, such as ATMs, keyboards, and credit cards, in images captured by first-person wearable devices. However, instead of assessing the whole scene in terms of privacy sensitivity, their systems only detected individual sensitive objects.

Raval et al. [RCS+14] presented *MarkIt*, a computer vision-based privacy marker framework that allowed users to use self-defined bounding boxes and hand-gestures to restrict visibility of content on two dimensional surfaces (e.g. white boards) or sensitive real-world objects. *iPrivacy* automatically detects privacy-sensitive objects from social images users are willing to share using deep multi-task learning [YZK+17]. It warns the image owners what objects in the images need to be protected before sharing and recommends privacy settings.

While all of these methods improved privacy, they either only did so post-hoc, i.e., after images had already been captured, or they required active user input. In contrast, our approach aims to prevent potentially sensitive imagery from being recorded at all, by proactively and automatically ensuring privacy in the background, i.e., without engaging the user. Unlike current computer vision based approaches that work in image space, e.g., by masking objects or faces [RCS+14; SZH18; YGE13], restricting access [KTC+16], or deleting recorded images post-hoc [TKC+14], we de-activate the camera completely using a mechanical shutter and also signal this to bystanders. Our approach is the first to employ eye movement analysis for camera re-activation that, unlike other sensing techniques (e.g., microphones, infra-red cameras), does not compromise the privacy of potential bystanders.

Contributions

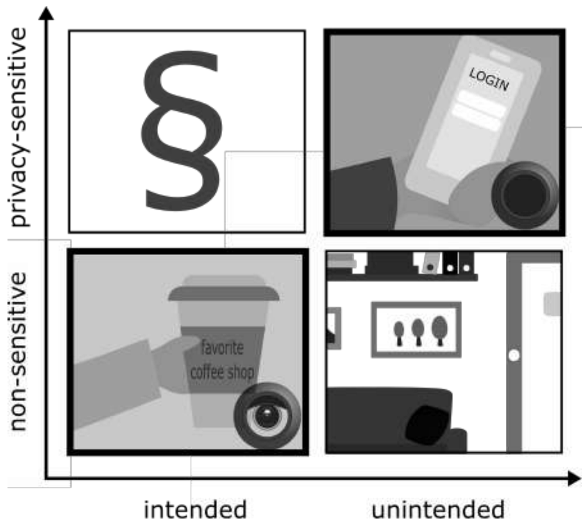
The specific contributions of this work are three-fold: First, we present PrivacEye, the first method that combines the analysis of egocentric scene image features with eye movement analysis to enable context-specific, privacy-preserving de-activation and re-activation of a head-mounted eye tracker's scene camera. As such, we show a previously unconfirmed transitive relationship: the users' eye movements are influenced by their current activity and environment. Simultaneously, the perceived privacy sensitivity of the situation they are in also depends on activity and environment [HIC+15]. We transitively relate privacy sensitivity and eye movements making use of activity and environment as common factor. Second, we evaluate our method on a data set of real-world mobile interactions and eye movement data, fully annotated with locations, activities, and privacy sensitivity levels of 17 participants. Third, we provide qualitative insights on the perceived social acceptability, trustworthiness, and desirability of PrivacEye, based on semi-structured interviews, using a fully functional prototype.

5.2.2 Design Rationale and Interaction Design

PrivacEye's design rationale is based on user and bystander goals and expectations. In this section, we outline how PrivacEye's design contributes to avoiding erroneous disclosure of sensitive information, so-called misclosures (User Goal 1), and social friction (User Goal 2), and detail on three resultant design requirements.

Goals and Expectations of Users & Bystanders

To illustrate the goals and expectations of users and bystanders and the resulting requirements, we use a fictive scenario with two main characters: Ada (a user of eye tracking enabled eyewear with PrivacEye) and Ben (an acquaintance) who assumes the bystander role. The subsequent narratives (in boxes) highlight where PrivacEye supports Ada in achieving her goals, namely avoiding the misclosure



(a)

Recording	Content	Examples
intended	non-sensitive	lifestyle shots, (live-) video (e.g., for lifelogging, social media), continuous camera stream (e.g., for tracking, localisation)
unintended	non-sensitive	uninteresting (e.g. flooring), blurry, or over-/underexposed imagery
intended	privacy-sensitive	secret photography (e.g. upskirts), or documentation purposes (e.g. accidents)
unintended	privacy-sensitive	incidental (e.g. bystanders) or inadvertent (e.g. login screens) captures of sensitive content

(b)

Figure 5.12: Systematisation (a), and examples (b) of types of imagery that are potentially captured by an "always-on" camera. PrivacEye reacts to *unintended, privacy-sensitive* imagery (Figure 5.12a, top right) with a closed shutter and to *intended, non-sensitive* imagery (Figure 5.12a, bottom left) with an open shutter.

(i.e. accidental disclosure [Cai09]) of sensitive data, being polite, and dodging social friction and conflict. In addition, we discuss what might have happened without PrivacEye's support in these situations.

> *While travelling, Ada uses the device to receive navigation hints, which utilize GPS and visual tracking based on images from the device's scene camera. The camera is "always-on" to capture important moments of her travel experiences and assist her with in-situ translation. Sensitive information, however, should not be captured. When Ada handles, e.g., her wallet or passport, the system automatically de-activates the camera and covers its lens with a shutter before she takes out her credit card or her passport number becomes visible.*

User Goal 1: Avoid Misclosure of Sensitive Data. A user wearing smart glasses with an integrated camera would typically do so to make use of a particular functionality, e.g., visual navigation. However, the device's "always-on" characteristic causes it to capture more than originally intended. Regarding the sensitivity of the content and recording intention, the captured imagery can be classified in a 2×2 matrix as depicted in Figure 5.12a. A navigation aid would require capturing certain landmarks for tracking and localization (*intended*, non-sensitive imagery). In addition also *unintended* imagery is captured. These images can be either uninteresting or useless (*unintended*, *non-sensitive*) or contain sensitive data (*unintended*, *privacy-sensitive*) (c.f., Hoyle et al. [HIC+15] and Korayem et al. [KTC+16]). For illustration, we list examples in Table 5.12b. Ideally, to prevent misclosures [Cai09], sensitive data should not be captured. However, requiring the user to constantly monitor her actions and environment for potential sensitive information (and then de-activate the camera manually) might increase the workload and cause stress. As users might be forgetful, misinterpret situations, or overlook privacy-sensitive items, automatic support from the system would be desirable from a user's perspective (c.f., Chapter 4).

> *The system also reacts to interpersonal conversations. So, when Ben approaches Ada in a café and they start to chat, it grants them privacy by de-activating the camera, which Ben can also infer from the closed shutter. While the first-person camera is de-activated, the system observes Ada's eye movements. When Ben leaves, or Ada puts her documents away and resumes another activity, e.g. sightseeing, the system detects a change in the privacy level from eye movement analysis and re-activates the first-person camera, without her having to think of it.*

User Goal 2: Avoid Social Friction. The smart glasses recording capabilities may cause social friction if they do not provide a clear indication whether the camera is on or off: Bystanders might even perceive device usage as a privacy threat when the camera is turned off [KKM15; KWB18]. In consequence, they feel uncomfortable around such devices [BCL+05; DDK14; EGA+15; KKM15]. Similarly, user experience is impaired when device users feel a need for justification as they could be accused of taking surreptitious pictures [HVC+15; KWB18]. In addition, automatic re-activation ensures that Ada does not forget to enable the camera manually, when leaving the café. While her forgetfulness might only impact localization performance for visual navigation, it might lead to "lost memories" and disappointment for a lifelogging use case.

Design Requirements

As a consequence of these user goals there are three essential design requirements that PrivacEye addresses: (1) The user can make use of the camera-based functionality without the risk of misclosures or leakage of sensitive information. (2) The system pro-actively reacts to the presence or absence of potentially privacy-sensitive situations and objects. (3) The camera device communicates the recording status clearly to both user and bystander.

5.2.3 PrivacEye Prototype

Our fully functional PrivacEye prototype, shown in Figure 5.13, is based on the PUPIL head-mounted eye tracker [KPB14] and features one 640×480 pixel camera (the so-called "eye camera") that records the right eye from close proximity (30 fps), and a second camera (1280×720 pixels, 24 fps) to record a user's environment (the so-called "scene camera"). The first-person (scene) camera is equipped with a fish eye lens with a 175° field of view and can be closed with a mechanical shutter. The shutter comprises a servo motor and a custom-made 3D-printed casing, including a mechanical lid to occlude the camera's lens. The motor and the lid are operated via a micro controller, namely a Feather M0 Proto (c.f., Section 5.1). Both cameras and the micro controller are connected to a laptop via USB. PrivacEye further consists of two main software components: (1) detection of privacy-sensitive situations to close the mechanical camera shutter and (2) detection of changes in user's eye movements that are likely to indicate suitable points in time for reopening the camera shutter.

Detection of Privacy-Sensitive Situations

The approaches for detecting privacy-sensitive situations we evaluated are (1) *CNN-Direct*, (2) *SVM-Eye*, and (3) *SVM-Combined*.

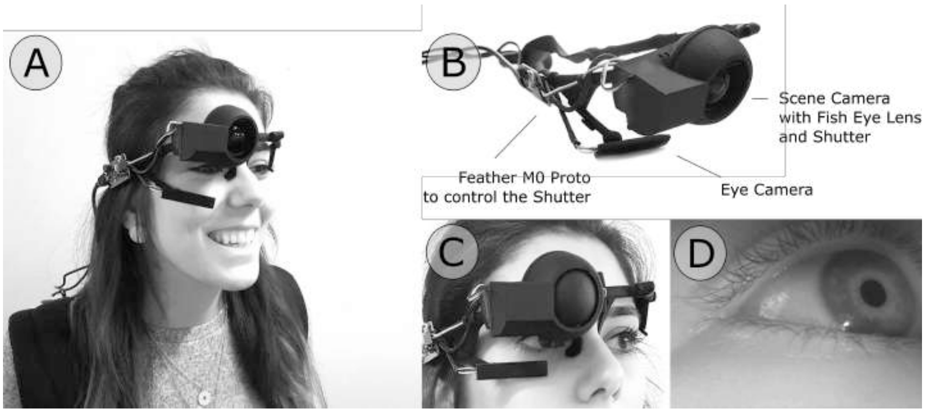


Figure 5.13: PrivacEye prototype with labeled components (B) and worn by a user with a USB-connected laptop in a backpack (A). Detection of privacy-sensitive situations using computer vision closes the camera shutter (C), which is reopened based on a change in the privacy detected level in a user's eye movements (D).

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CNN-Direct. Inspired by prior work on predicting privacy-sensitive pictures posted in social networks [OSF17], we used a pre-trained GoogLeNet, a 22-layer deep convolutional neural network [SLJ+14]. We adapted the original GoogLeNet model for our specific prediction task by adding two additional fully connected (FC) layers. The first layer was used to reduce the feature dimensionality from 1024 to 68 and the second one, a Softmax layer, to calculate the prediction scores. Output of our model was a score for each first-person image indicating whether the situation visible in that image was privacy-sensitive or not. The cross-entropy loss was used to train the model. The full network architecture is illustrated in Figure 5.14.

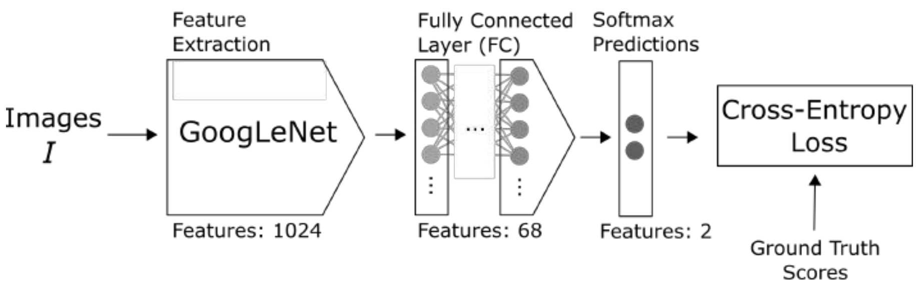


Figure 5.14: Our method for detecting privacy-sensitive situations is based on a pre-trained GoogleNet model that we adapted with a fully connected (FC) and a Softmax layer. Cross-entropy loss is used for training the model.

SVM-Eye. Given that eye movements are independent from the scene camera's shutter status, they can be used to (1) detect privacy-sensitive situations while the

Fixation (8)	rate, mean, max, var of durations, mean/var of mean/var pupil position within one fixation
Saccades (12)	rate/ratio of (small/large/right/left) saccades, mean, max, variance of amplitudes
Combined (1)	ratio saccades to fixations
Wordbooks (24)	number of non-zero entries, maximum and minimum entries as well as their difference for n-grams with $n <= 4$
Blinks (3)	rate, mean/var blink duration
Pupil Diameter (4)	mean/variance of mean/variance during fixations

Table 5.1: We extracted a total of 52 eye movement features to describe a user's visual behaviour. The number of features per category is given in parentheses.

camera shutter is open and (2) detect changes in the subjective privacy level while the camera shutter is closed. The goal of this second component is to instead detect changes in a user's eye movements that are likely linked to changes in the privacy sensitivity of the current situation and thereby to keep the number of times the shutter is reopened as low as possible. To detect privacy-sensitive situations and changes, we trained a support vector machine (SVM) with a radial-basis function (RBF) kernel on characteristic eye movement features, which we extracted using only the eye camera video data. We extracted a total of 52 eye movement features, covering fixations, saccades, blinks, and pupil diameter (see Table 5.1 for a list and description of the features). Similar to [BWG+11], each saccade is encoded as a character forming words of length n (wordbook). We extracted these features using a sliding window of 30 seconds (step size of 1 sec).

SVM-Combined. A third approach for the detection of privacy-sensitive situations is a hybrid method. We trained a SVM classifier using the extracted eye movement features (52) and combined them with CNN features (68) from the scene image, which we extracted from the first fully connected layer of our trained CNN model, creating feature vectors of size 120. With the concatenation of eye movement and scene features, we are able to combine the information from the two previous approaches during recording phases where the camera shutter is open.

Data Set and Annotation

While an ever-increasing number of eye movement data sets have been published in recent years [SB15a; BWG+11; BWG12; HLM+18; SB15b], none of them focused on privacy-related attributes. We therefore make use of a previously recorded

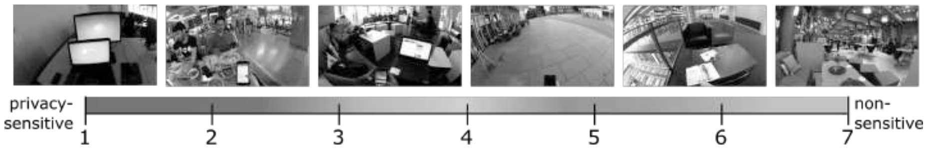


Figure 5.15: Sample images showing daily situations ranging from "privacy-sensitive", such as password entry or social interactions, to "non-sensitive", such as walking down a road or sitting in a café.

# Question	Example Annotation
1. What is the current environment you are in?	office, library, street, canteen
2. Is this an indoor or outdoor environment?	indoor, outdoor
3. What is your current activity in the video segment?	talking, texting, walking
4. Are private objects present in the scene?	schedule, notes, wallet
5. Are devices with potentially sensitive content present in the scene?	laptop, mobile phone
6. Is a person present that you personally know?	yes, no
7. Is the scene a public or a private place?	private, public, mixed
8. How appropriate is it that a camera is in the scene?	Likert scale (1: fully inappropriate to 7: fully appropriate)

Table 5.2: Annotation scheme used by the participants to annotate their recordings.

data set by Steil et al. [SMS+18]. The data set of Steil et al. contains more than 90 hours of data recorded continuously from 20 participants (6f, 12m, 0d, aged 22-31) over more than four hours each. Participants were students with different backgrounds and subjects with normal or corrected-to-normal vision. During the recordings, participants roamed a university campus and performed their everyday activities, such as meeting people, eating, or working as they normally would on any day at the university. To obtain some data from multiple, and thus also privacy-sensitive, places on the university campus, participants were asked to not stay in one place for more than 30 minutes. Participants were further asked to stop the recording after about one and a half hours so that the laptop's battery packs could be changed and the eye tracker re-calibrated. This yielded three recordings of about 1.5 hours per participant. Participants regularly interacted with a mobile phone provided to them and were also encouraged to use their own laptop, desktop computer, or music player if desired. The data set thus covers a rich set of representative real-world situations, including sensitive environments and tasks. The data collection was performed with the same equipment as shown in Figure 5.13 excluding the camera shutter.

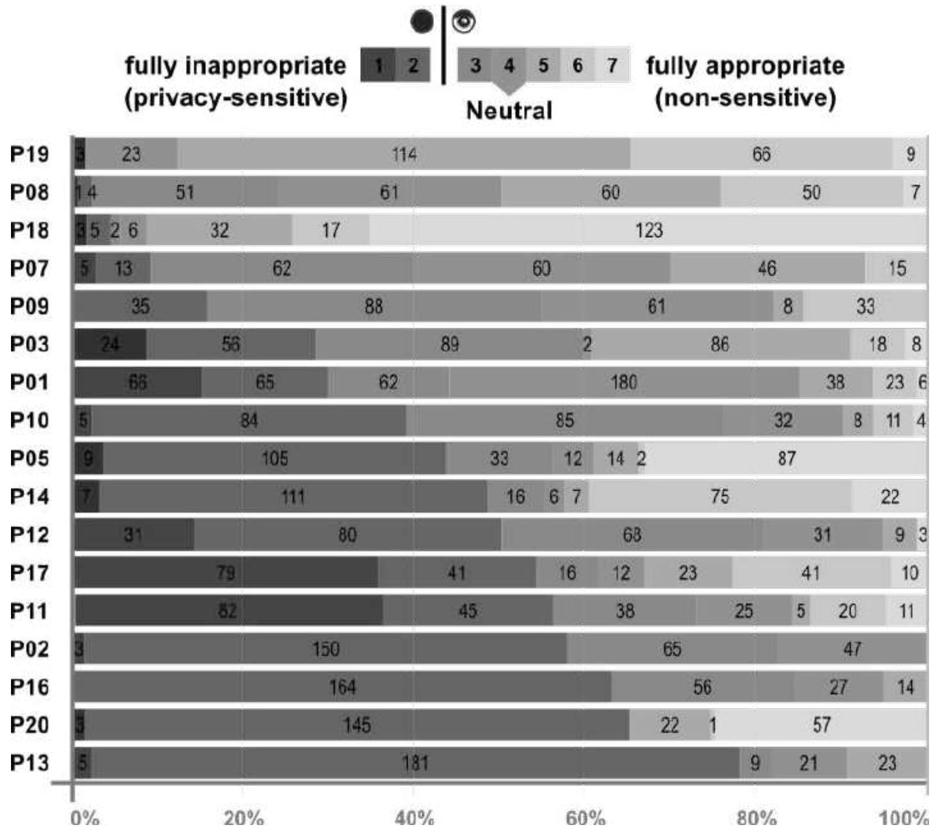


Figure 5.16: Privacy sensitivity levels rated on a 7-pt Likert scale from 1: fully inappropriate (i.e., privacy-sensitive) to 7: fully appropriate (i.e., non-sensitive). Distribution in labeled minutes per level per participant, sorted according to a "cut-off" between closed shutter (level 1 to 2) and open shutter (level 3 to 7). In practice, the "cut-off" level could be chosen according to individual ratings as measured by the Privacy Attitudes Questionnaire, PAQ.

We created a new annotation scheme for the pre-existing data set by Steil et al. [SMS+18]. The data set was fully annotated by the participants themselves with continuous annotations of location, activity, scene content, and subjective privacy sensitivity level. 17 out of the 20 participants finished the annotation of their own recording resulting in about 70 hours of annotated video data. They again gave informed consent and completed a questionnaire on demographics, social media experience and sharing behavior (based on Hoyle et al. [HTA+14]), general privacy attitudes, as well as other-contingent privacy [BC14a] and respect for bystander privacy [PSC+17]. General privacy attitudes were assessed using the *Privacy Attitudes Questionnaire* (PAQ), a modified Westin Scale [Wes03] as used in previous studies by [Cai09; PSC+17].

Annotations were performed using Advene [APS12]. Participants were asked to annotate continuous video segments showing the same situation, environment, or activity. They could also introduce new segments in case a privacy-relevant feature in the scene changed, e.g., when a participant switched to a sensitive application on their mobile phone. Participants were asked to annotate each of these segments according to the annotation scheme (see Table 5.2). Privacy sensitivity was rated on a 7-point Likert scale ranging from 1 (fully inappropriate) to 7 (fully appropriate). We provide examples in Figure 5.15. As we expected our participants to have difficulties understanding the concept of “privacy sensitivity”, we rephrased it for the annotation to “How appropriate is it that a camera is in the scene?”. Figure 5.16 visualizes the labeled privacy sensitivity levels for each participant. Based on the latter distribution, we pooled ratings of 1 and 2 in the class “privacy-sensitive”, and all others in the class “non-sensitive”. A consumer system would provide the option to choose this “cut-off”. We will use these two classes for all evaluations and discussions that follow in order to show the effectiveness of our proof-of-concept system. The dataset is available at `https://www.mpi-inf.mpg.de/MPIIPrivacEye/`.

5.2.4 Proof-of-Concept Evaluation

We evaluated the different approaches on their own and in combination in a realistic temporal sequential analysis trained in a person-specific (leave-one-recording-out) and person-independent (leave-one-person-out) manner. We assume that the camera shutter is open at start up. If no privacy-sensitive situation is detected, the camera shutter remains open and the current situation is rated “non-sensitive”, otherwise, the camera shutter is closed and the current situation is rated “privacy-sensitive”. Finally, we analyze error cases and discuss the performance of PrivacEye in different environments and activities.

Sequential Analysis

To evaluate PrivacEye, we applied the three proposed approaches separately as well as in combination in a realistic temporal sequential analysis, evaluating the system as a whole within person-specific (leave-one-recording-out) and person-independent (leave-one-person-out) cross validation schemes. Independent of CNN or SVM approaches, we first trained and then tested in a person-specific fashion. That is, we trained on two of the three recordings of each participant and tested on the remaining one – iteratively over all combinations and averaging the performance results in the end. For the leave-one-person-out cross validation, we trained on the data of 16 participants and tested on the remaining one. *SVM-Eye* is the only one of the three proposed approaches that allows PrivacEye to be functional when no scene imagery is available, i.e., when the shutter is closed. Additionally, it can be applied when the shutter is open, thus serving both software components of PrivacEye. While the camera shutter is not closed, i.e., scene imagery is available, *CNN-Direct* or *SVM-Combined* can be applied. To provide a comprehensive picture, we then analyzed the combinations (1 + 2) *CNN-Direct* + *SVM-Eye* (*CNN-D./SVM-E.*) and (3 + 2) *SVM-Combined* + *SVM-Eye* (*SVM-C./SVM-E.*). For each of the combinations, the first approach is applied when the camera shutter is open and *SVM-Eye* only when the shutter is closed. For the sake of completeness, we also evaluated *SVM-Combined* and *CNN-Direct* on the whole data set (including scenes where the camera shutter would be closed). We stress that these represent hypothetical scenarios in which eye and scene features are always available, even when the camera shutter is closed. As this is in practice not possible, they have to be seen as baselines for which all information is available. For evaluation purposes, we apply the proposed approaches within a step size of one second in a sequential manner. The previously predicted camera shutter position (open or close) decides which approach is applied for the prediction of the current state to achieve realistic results. We use

$$Accuracy = \frac{TP+TN}{TP+FP+TN+FN},$$

where TP, FP, TN, and FN count sample-based true positives, false positives, true negatives, and false negatives, as performance indicator. Through out this analysis "positive" indicates that a privacy-sensitive situation, i.e., a need to act and close the shutter, has been identified.

Results

In the following we report results for the person-specific and leave-one-person-out evaluation. We compare the performance of these three approaches, namely (1) *CNN-Direct*, (2) *SVM-Eye*, and (3) *SVM-Combined* against the combinations (1+2) *CNN-D./SVM-E.*, (3+2) *SVM-C./SVM-E.*, and a Majority Classifier (Table 5.3).

The results reveal that all trained approaches and combinations perform above the majority class classifier in the person-specific evaluation, but only *SVM-Eye*

	Features available		Accuracy	
	Scene	Eye	p.-specific	p.-independent
(1) CNN-Direct*	✔		68.2%	57.8%
(2) SVM-Eye		✔	72.0%	**61.2%**
(3) SVM-Combined*	✔	✔	70.4%	59.3%
(1+2) CNN-D./SVM-E.	(✔)	✔	71.6%	59.3%
(3+2) SVM-C./SVM-E.	(✔)	✔	**73.0%**	58.9%
Majority**			64.9%	61.0%

*) Evaluated on the whole data set with all information available at any time, i.e., where scene imagery is available with the camera shutter closed.
**) Majority classifier which always decides for the class that is in the majority in the respective training set, i.e., non-sensitive.

Table 5.3: Performance (accuracy) of the tested approaches: (1) *CNN-Direct*, (2) *SVM-Eye*, and (3) *SVM-Combined* and their combinations. We mark available features with ✔. In case of the combined approaches, (✔) indicates that scene features are used when available to (1) or (3), respectively. If unavailable (i.e., when the camera shutter is closed), *SVM-Eye* (2) is employed.

beats the majority classifier in the person-independent evaluation. In the person-specific evaluation, *SVM-Eye* and *SVM-Combined* perform quite robustly, around 70% accuracy. The interplay approach *SVM-C./SVM-E.*, which we included in our prototype, exceeds 73% outperforms all other combinations in terms of accuracy. One reason for the performance improvement of *SVM-C./SVM-E.* in comparison to its single components is that *SVM-Combined* performs better for the detection of privacy-sensitive situations when the camera shutter is open while *SVM-Eye* performs better for preserving privacy-sensitive situations so that the camera shutter remains closed. The more challenging task, which assumes that privacy-sensitivity could generalize over multiple participants, is tested in the person-independent leave-one-person-out cross validation. Similar to the person-specific evaluation, *CNN-Direct* and *CNN-D./SVM-E.* perform worse than the other approaches. Here, *SVM-Eye* outperforms *SVM-Combined* and *SVM-C./SVM-E.*. However, overall performance is limited. The comparison between the results of the person-specific, and the person-independent evaluation confirms that privacy sensitivity is highly individual (see also Figure 5.16), and that generalization is challenging.

A comparison of the best performing approach, *SVM-C./SVM-E.* against a Minority and a Majority Classifier reveals the merit of PrivacEye as a compromise between privacy risk and usability issue (Figure 5.17). The majority classifier always decides for the class that is the majority of the training set, i.e., non-sensitive.

Thus the majority classifier represents current state-of-the-art smart glasses: the "always-on" camera considers all situations as equally non-sensitive. In contrast, the minority classifier always decides for the class that is the minority of the training set, i.e., sensitive. This might be viewed as representative for hypothetical cases where smart glasses usage is forbidden. In these cases privacy risk is kept at zero, but usability is impaired. With 16% false negatives (FN) and 12% false positives (FP) PrivacEye constitutes a superior compromise between privacy risk and usability issues. Nevertheless, we acknowledge that the performance of the current implementation is (not yet) optimal, and that FN and FP $> 1\%$ would be desirable.

Error Case Analysis

For PrivacEye, it is not only important to detect the privacy-sensitive situations (TP), but equally important to detect non- sensitive situations (TN), which are relevant to grant a good user experience. Our results suggest that the combination *SVM/SVM* performs best for the person-specific case. For this setting we carry out a detailed error case analysis of our system for the participants' different activities. In Figure 5.18 we go into detail on the occurrence of false positives, i.e., cases where the camera is de-activated in a non-sensitive situation, as well as false negatives, i.e., cases where the camera remains active although the scene is privacy-sensitive. Examples as provided in Figure 5.19 show that, while false positives would be "only" inconvenient in a realistic usage scenario, false negatives are critical and might lead to accidental disclosure of sensitive information. Thus, our argumentation focuses on eliminating false negatives.

Figure 5.18 provides a detailed overview of true positives and false negatives with respect to the labeled activities. For each label two stacked bars are shown: PrivacEye's prediction (top row) and the ground truth annotation (GT, bottom row). The prediction's result defines the "cut-off" between closed shutter (left, privacy-sensitive) and open shutter (right, non-sensitive), which is displayed as vertical bar. Segments that were predicted to be privacy-sensitive, include both true positives (TP, red) and false positives (FP, yellow-green) are shown left of the "cut-off". Similarly, those segments that were predicted to be non-sensitive, including true negatives (TN, yellow-green) and false negatives (FN, red), are displayed right of the "cut-off". While false positives (FP) (i.e., non-sensitive situations classified as sensitive) are not problematic, as they to not create privacy risks, false negatives (FN) are critical. A comparison of true positives (TP) and false negatives (FN) shows that PrivacEye performs well within most environments, e.g., offices or corridors. In these environments true positives outweigh false negatives. However, in the computer room environment, where a lot of screens with potentially problematic content (which the wearer might not even be aware of at recording time) are present, performance drops. Misclassification between personal displays, e.g., laptops and public displays (e.g. room occupancy plans) are a likely reason for the larger amount of false negatives (FN). Future work

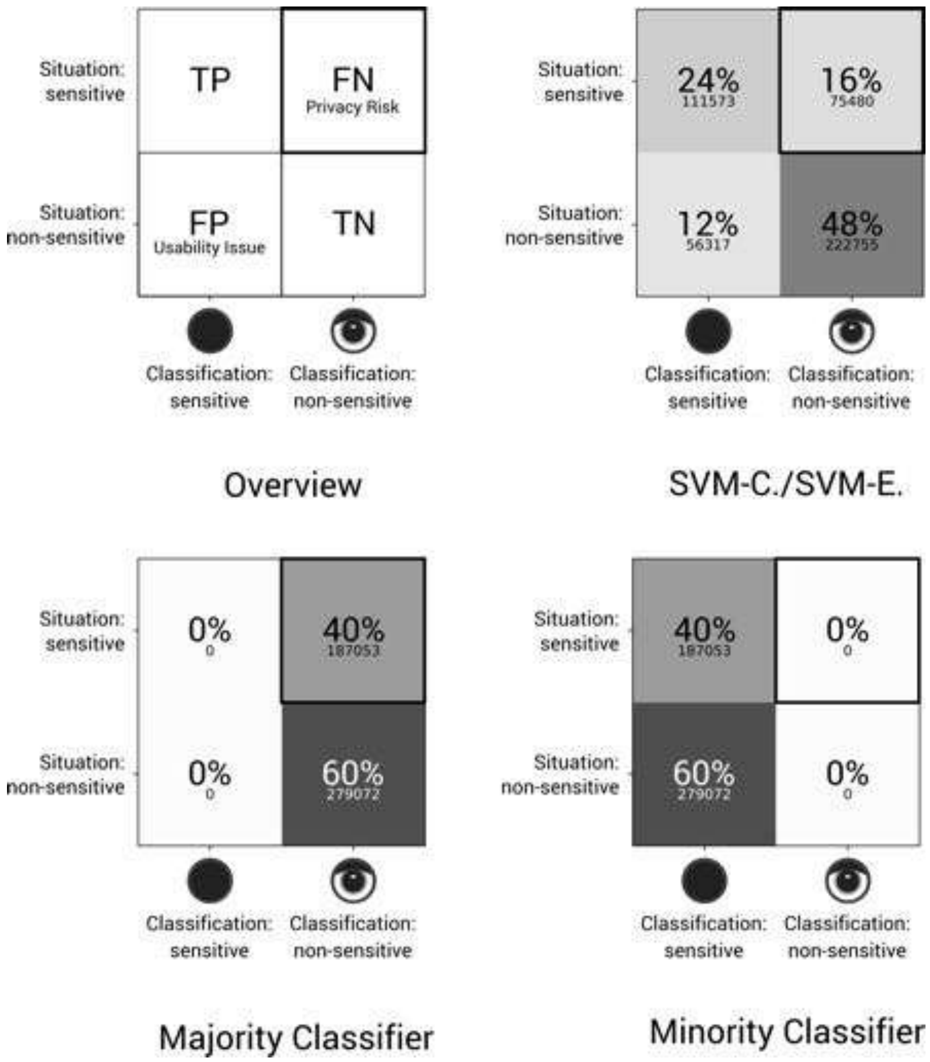


Figure 5.17: Confusion matrices, each with true positives (TP), false negatives (FN), false positives (FP), and true negatives (TN) as illustrated in the overview (top, left). SVM-C./SVM-E (top, right) present a trade-off between the majority classifier (bottom, left), i.e., shutter always open or state-of-the-art smart glasses, and the minority classifier (bottom, right), i.e., shutter always closed or smart glasses forbidden.

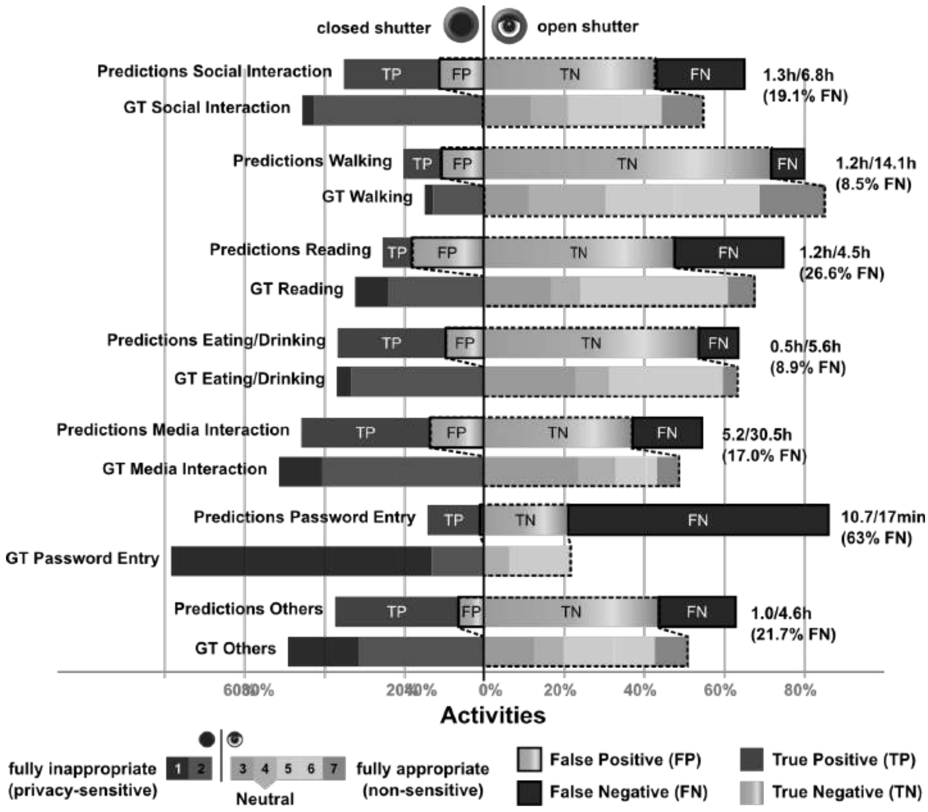


Figure 5.18: Error case analysis for different and activities showing the "cut-off" between closed shutter (left, *privacy-sensitive*) and open shutter (right, *non-sensitive*) with PrivacEye prediction and the corresponding ground truth (GT). False positives (FP) are *non-sensitive* but protected (closed shutter), false negatives (FN) are *privacy-sensitive* but unprotected (open shutter).

might aim to combine PrivacEye with an image-based classifier trained for screen contents (c.f., Korayem et al. [KTC+16]), which, however, would come at the cost of excluding also non-sensitive screens from the footage. Future work might specifically target these situations to increase accuracy.

As also outlined in Figure 5.18, PrivacEye works best while eating/drinking and in media interactions. Also, the results are promising for detecting social interactions. The performance for password entry, however, is still limited. Although the results show that it is possible to detect password entry (true positives, TP), the amount of false negatives (FN) is high compared to other activities. This is likely caused by the data set's under-representation of this activity, which characteristically lasts only a few seconds. Future work might be able to eliminate this by specifically training for password and PIN entry, which will enable the classifier to better distinguish between PIN entry and, e.g., other media interactions. While PrivacEye correctly identifies social interactions, and screen interactions as privacy-sensitive, false positives (FP) contain reading a book or standing in front of a public display. In these cases PrivacEye would act too restrictively. Here, de-activating the camera might lead to a loss of functionality: for instance if the camera would de-activate during reading, in-situ translation (c.f., Section 1.2) would become unavailable. While future work would naturally strive to eliminate these cases, reducing the number of false positives, typically comes at the cost of an increased risk of false negatives: sensitive situations then are classified as unproblematic, which causes a potential privacy risk. Thus, future work would aim to keep false negatives (FN), i.e., privacy risks, as low as possible, while relaxing requirements on false positives (FP). In consequence, future implementations would have to additionally provide an option for manual re-activation.

5.2.5 User Feedback

Collecting initial subjective feedback during early stages of system development allows us to put research concepts in a broader context and helps to shape hypotheses for future quantitative user studies. In this section, we report on a set of semi-structured one-to-one interviews on the use of head-worn augmented reality displays in general, and our interaction design and prototype in particular. To obtain the user feedback, we recruited 12 participants (6f, 6m), aged 21 to 31 years (M=24, SD=3) from the local student population, and distinct from the participants in the annotation task. They were enrolled in seven highly diverse majors, ranging from computer science and biology to special needs education. We decided to recruit students, given that we believe they and their peers are potential users of a future implementation of our prototype. We acknowledge that this sample, consisting of rather well educated young adults (with six of them having obtained a Bachelor's degree), is not representative for the general population. Interviews lasted about half an hour and participants received a 5 Euro Amazon voucher.

(a) True positives (b) False positives

(c) False negatives (d) True negatives

Figure 5.19: Examples for (a) correct detection of "privacy-sensitive" situations, (b) incorrect detection of "non-sensitive" situations, (c) incorrect detection of "privacy-sensitive" situations, and (d) correct detection of "non-sensitive" situations.

Interview Protocol

During the interviews, participants were encouraged to interact with state-of-the-art head-mounted displays (Vuzix M300 and Sony SmartEyeglass) and our prototype. Participants were presented with the fully functional PrivacEye prototype, which was used to illustrate three scenarios: 1) interpersonal conversations, 2) sensitive objects (a credit card and a passport), and 3) sensitive contents on a device screen. Due to the time required to gather person-specific training data for each interviewee as well as run time restrictions, the scenarios were presented using the Wizard-of-Oz method. This is also advantageous, as the laboratory-style study environment – with white walls, an interviewer and no distractors present – might have induced different eye movement patterns than a natural environment. Also, potential errors of the system, caused by its prototypical implementation, might have caused the participants' bias toward the concept. To prevent these issues, the shutter was controlled remotely by an experimental assistant. This way, the interviewees commented on the concept and vision of PrivacEye and not on the actual proof-of-concept implementation, which – complementing the afore-described evaluation – provides a more comprehensive and universal set of results altogether. The semi-structured interview was based on the following questions:

Q1 *Would you be willing to wear something that would block someone from being able to record you?*

Q2 *If technically feasible, would you expect the devices themselves, instead of their user, to protect your privacy automatically?*

Q3 *Would you feel different about being around someone who is wearing those kinds of intelligent glasses than about those commercially available today? Why?*

Q4 *If you were using AR glasses, would you be concerned about accidentally recording any sensitive information belonging to you?*

Q5 *How would you feel about (such) a system automatically taking care that you do not capture any sensitive information?*

Q6 *How do you think the eye tracking works? What can the system infer from your eye data?*

Q7 *How would you feel about having your eye movements tracked by augmented reality glasses?*

The questions were designed following a “funnel principle”, with increasing specificity towards the end of the interview. We started with four more general questions (not listed above), such as “Do you think recording with those glasses is similar or different to recording with a cell phone? Why?”, based on [DDK14]. This provided the participant with some time to familiarize herself with the topic before being presented with the proof-of-concept prototype (use case “bystander privacy”) after Q1 and the use cases “sensitive objects” (e.g., credit card, passport) and “sensitive data” (e.g. login data) after Q4. Eye tracking functionality was demonstrated after Q5. While acquiescence and other forms of interviewer effects cannot be ruled out completely, this step-by-step presentation of the prototype and its scenarios ensured that the participants voiced their own ideas first, before being directed towards discussing the actual concept of the PrivacEye prototype. Each participant was asked for his/her perspectives on the PrivacEye’s concept (Q2-Q5) and eye tracking (Q6 and Q7). The interviews were audio recorded and transcribed for later analysis. Subsequently, qualitative analysis was performed following inductive category development [May14]. Key motives and reoccurring themes were extracted and are presented in this section.

Results

Subsequently, we link the interviews back to PrivacEye’s design and discuss implications for future work.

User Views on Responsibility

When we designed PrivacEye, we aimed to locate all required sensing and hardware on the user's side, relieving the bystander of the responsibility to protect his/her privacy. However, similar to the interviewees of Denning et al. [DDK14], the majority of our participants expressed interest in technologies that would allow them to actively block others from recording them (*Blocking:yes*, n=7). Participants' comments on the use cases further indicated that they found the "bystander privacy" use case much less convincing than the other two user-centered use cases. We attribute this to PrivacEye providing a lack of control from a bystander's perspective. Nevertheless, for future applications, a combination of both technologies, a blocking capability on the bystander side and a technology similar to PrivacEye, would be more inclusive (e.g., for those without token) or could serve as a fall-back in the case of compatibility issues between eye tracking enabled smart glasses and blocking devices.

User Views on Transparency

Making it transparent (using the 3D-printed shutter), whether the camera was turned on or off, was valued by all participants. Seven participants found the integrated shutter increased perceived safety in contrast to current smart glasses; only few participants stated that they made no difference between the shutter and other visual feedback mechanisms, e.g., LEDs (n=2). Several participants noted that the physical coverage increased trustworthiness because it made the system more robust against hackers (*concerns:hacking*, n=3) than LEDs. Concluding, the usage of physical occlusion could increase perceived safety and, thus, could be considered an option for future designs. Participants even noted that the usage of the shutter as reassuring as pasting up a laptop camera (*laptop comparison*, n=4), which is common practice.

Perceived Trustworthiness

In contrast, participants also expressed technology scepticism, particularly that the system might secretly record audio (*concerns:audio*, n=5) or malfunction (*concerns:malfunction*, n=4). With the increasing power of deep neural networks malfunctions, system failures, or inaccuracies will be addressable in the future, interaction designers will have to address this fear of "being invisibly audio-recorded". A lack of knowledge about eye tracking on both the user's and the bystander's side might even back this misconception. Therefore, future systems using eye tracking for context recognition will have to clearly communicate their modus operandi.

Perceived Privacy of Eye Tracking

The majority of participants claimed to have no privacy concerns about smart glasses with integrated eye tracking functionality: *"I do see no threat to my privacy or the like from tracking my eye movements; this [the eye tracking] would rather be something which could offer a certain comfort"* (P11). Only two participants expressed concerns about their privacy, e.g., due to fearing eye-based emotion recognition (P3). One was uncodeable. This underlines our assumption that eye tracking promises privacy-preserving and socially acceptable sensing in head-mounted augmented reality devices and, thus, should be further explored.

Desired Level of Control

Participants were encouraged to elaborate on whether the recording status should be user-controlled or system-controlled. P10 notes: *"I'd prefer if it was automatic, because if it is not automatic, then the wearer can forget to do that [de-activating the camera]. Or maybe he will say 'Oh, I do not want to do that' and then [...] that leads to a conflict. So better is automatic, to avoid questions"*. Four other participants also preferred the camera to be solely controlled by the system (*control:automatic*, n=4). Their preference is motivated by user forgetfulness (n=5), and potential non-compliance of users (in the bystander use case, n=1), and increased practicality for the user (n=5): *"That would be like a safety net, like for the own forgetfulness. [...] one pulls out of one's bag so unconsciously and types in the PIN one so often ... I think you usually do not know if you have just entered a PIN or not"* (P5). Only two participants expressed a preference for sole (*control:manual*) control, due to an expected lack of system reliability, and technical feasibility. Two responses were uncodable. All other participants requested to implement manual confirmation of camera de-activation/re-activation or manual operation as alternative modes (*control:mixed*, n=4), i.e., they like to feel in control. To meet these user expectations, future interaction designs would have to find an adequate mix of user control and automatic support through the system; for example, by enabling users to explicitly record sensitive information (e.g., in cases of emergency) or label seemingly non-sensitive situations "confidential".

5.2.6 Discussion

We discuss PrivacEye in light of the aforementioned design and user requirements and results of the technical evaluation. In addition, we outline chances for future research arising from the technical limitations of our current proof-of-concept prototype.

Privacy Preserving Device Behaviour

Design Requirements 1 and *2* demand privacy-preserving device behaviour. With PrivacEye, we have presented a computer vision routine that analyses all imagery obtained from the scene camera, combined with eye movement features with regard to privacy sensitivity and, in case a situation requires protection, the ability to de-activate the scene camera and close the system's camera shutter. This approach prevents both accidental misclosure and malicious procurement (e.g. hacking) of sensitive data, as has been positively highlighted by our interview participants. However, closing the shutter comes at the cost of having the scene camera unavailable for sensing after it has been de-activated. PrivacEye solves this problem by using a second eye camera that allows us, in contrast to prior work, to locate all required sensing hardware on the user's side. With PrivacEye we have provided proof-of-concept that context-dependent re-activation of a first-person scene camera is feasible using only eye movement data. Future work will be able to build upon these findings and further explore eye tracking as a sensor for privacy-enhancing technologies. Furthermore, our results provide first prove that there is indeed a transitive relationship over privacy sensitivity and a user's eye movements.

Defining Privacy Sensitivity

Prior work indicates that the presence of a camera may be perceived appropriate or inappropriate depending on social context, location, or activity [HTA+14; HIC+15; PSC+17]. However, related work does, to the best of our knowledge, not provide any insights on eye tracking data in this context. For this reason, we run a dedicated data collection and ground truth annotation. Designing a practicable data collection experiment requires the overall time spent by a participant for data recording and annotation to be reduced to a reasonable amount. Hence, we made use of an already collected data set, and re-invited the participants only for the annotation task. While the pre-existing data set provided a rich diversity of privacy-sensitive locations and objects, including smart phone interaction, and realistically depicts everyday student life, it is most likely not applicable to other contexts, e.g., industrial work or medical scenarios.

For PrivacEye, we rely on a 17-participant-large, ground truth annotated dataset with highly realistic training data. Thus, the collected training data cannot be fully generalized, e.g., to other regions or age groups. On the plus side, however, this data already demonstrates that in a future real-world application, sensitivity ratings may vary largely between otherwise similar participants. This might also be affected by their (supposedly) highly individual definition of "privacy". Consequently, a future consumer system might be pre-trained and then adapted online, based on personalized retraining after user feedback. In addition, users should be enabled to select their individual "cut-off", i.e., the level from which a recording is blocked, which was set to "2" for PrivacEye. Future users of consumer devices might choose more rigorous or relaxed "cut-off" levels depending on their personal preference. Initial user feedback also indicated that an interaction design that combines automatic, software-controlled de- and re-activation, with conscious control of the camera by the user, could be beneficial.

Eye Tracking for Privacy-Enhancement

Eye tracking is advantageous for bystander privacy given that it only senses users and their eye movements. In contrast to, e.g., microphones or infra-red sensing, it senses a bystander and/or an environment only indirectly via the user's eye motion or reflections. Furthermore, eye tracking allows for implicit interaction and is non-invasive, and we expect it to become integrated into commercially available smart glasses in the near future. On the other hand, as noted by Liebling and Preibusch [LP14; Pre14], eye tracking data is a scare resource, which can be used to identify user attributes like age, gender, health, or user's current task. For this reason, the collection and use of eye tracking data could be perceived as a potential threat to user privacy. However, our interviews showed that eye tracking was not perceived as problematic by a large majority of our participants. Nevertheless, we stress that eye tracking data must be protected by appropriate privacy policies and data hygiene. Particularly, as the interviews also illustrate that users – being unaware of potential threats – are unlikely to take action themselves. Thus, in order to not trade one type of privacy impairment (the user's) for another (the bystander's), approaches that increase eye tracking privacy without user effort, e.g., through differential privacy [LXD+19; SHH+19], will become necessary.

To use our proposed hardware prototype in a real-world scenario, data sampling and analysis need to run on a mobile phone. The CNN feature extraction is currently the biggest computational bottleneck, but could be implemented in hardware to allow for real-time operation (c.f., Qualcom's Snapdragon 845). Further, we believe that a consumer system should provide an accuracy >90% which could be achieved using additional sensors such as GPS or inertial tracking. However, presenting the first approach for automatic de- and re-activation of a first-person camera that achieves ∼73% with competitive performance to *ScreenAvoider* (54.2 - 77.7%) [KTC+14] and *iPrivacy* (∼75%) [YZK+17], which are restricted to scene content protection and post-hoc privacy protection, we provide a solid basis for follow up work. We note that a generalized person-independent model for privacy sensitivity protection is desirable. For this work only the participants themselves labelled their own data. Aggregated labels of multiple annotators would result in a more consistent and generalizable "consensus" model and improve test accuracy, but would dilute the measure of perceived privacy sensitivity, which is highly subjective [PSC+17]. Specifically, similar activities and environments were judged differently by the individual participants, as seen in Figure 5.16. The availability of this information is a core contribution of our data set.

Communicating Privacy Protection

The interaction design of PrivacEye tackles *Design Requirement 3* using a non-transparent shutter. Ens et al. [EGA+15] reported that the majority of their participants expected to feel more comfortable around a wearable camera device if it clearly indicated to be turned on or off. Hence, our proposed interaction design aims to improve a bystander's awareness of the recording status by employing an *eye metaphor*. Our prototype implements the "eye lid" as a retractable shutter made from non-transparent material: open when the camera is active, closed when the camera is inactive. Thus, the metaphor mimics "being watched" by the camera. The "eye lid" shutter ensures that bystanders can comprehend the recording status without prior knowledge, as eye metaphors have been widely employed for interaction design, e.g., to distinguish visibility or information disclosure [MC16; PIF+04; SKL11] or to signal user attention [CM17]. Furthermore, in contrast to visual status indicators, such as point lights (LEDs), physical occlusion is non-spoofable (c.f., [DDK14; PLE+15]). This concept has been highly appreciated during our interviews, which is why we would recommend adopting it for future hardware designs.

5.2.7 Summary

In this section, we presented PrivacEye, a method that combines first-person computer vision with eye movement analysis to enable context-specific, privacy-preserving de-activation and re-activation of a head-mounted eye tracker's scene camera. We have evaluated our method quantitatively on data set of fully annotated everyday behavior (N=17) as well as qualitatively, by collecting subjective user feedback from 12 potential future users. Our evaluations and interviews demonstrated both the technical feasibility and practical appeal of PrivacEye, which can be understood as a proof-of-concept of eye tracking-enabled, privacy-sensitive smart glasses. To the best of our knowledge, our method is the first of its kind and prevents potentially sensitive imagery from being recorded at all, without the need for active user input. As such, we believe the method opens up a new and promising direction for future work in head-mounted eye tracking, the importance of which will only increase with further miniaturization and integration of eye tracking in consumer smart glasses.

5.3 Summary and Conclusion

With this chapter we explored HCD's *Prototype* phase. From the previous phase, *Ideate & Design* we identified the provision of proactive, contextual and reassuring mechanisms as contributors to socially acceptable designs. We explored reassuring, "candid", status indicators for body-worn cameras through a range of prototyping efforts. We contribute an annotated portfolio reflecting on these prototyping efforts where we highlight the challenge of striking trade-offs between fidelity, size, and functionality. Our portfolio exemplifies how combining a range of different prototyping approaches can contribute to a better integration of social acceptability considerations in HCD. Specifically, how empirical findings can evolve into prototypes. In Section 5.2 we evolve this line of thinking and present one proof-of-concept prototype, PrivacEye. PrivacEye's interaction design is based on insights gathered during HCD's *Observe & Understand* and *Ideate & Design* that are developed into a fully functional prototype. The design's proactivity and reassuring mechanisms were received positively by participants (N=12). From a technical perspective we were able to proof a transitive relationship between eye movement, activity, and privacy-sensitivity. We provide proof-of-concept that this transitivity can be used for camera deactivation and re-activation based in a user's eye movements.

5.3.1 Limitations

In this chapter we presented prototypes. Their most striking, but also most self-evident limitation is that they are prototypical, i.e., they do not possess the look-and-feel or size of final products. All of our prototypes were build to test approaches for proactive device behavior (e.g., by reacting to conversations [MSK+18]), and methods and metaphors for camera status communication (e.g., occlusion of the lens). In consequence, they focused on understandability, and increasing privacy and trust instead of aesthetics or fashion-compatibility. Specifically, we did not build mock-ups that resemble the appearance of a finished article as common in e.g., Industrial Design (c.f., Holmquist [Hol05]). Nevertheless, aspects of fashion, "coolness" or aesthetics have been shown to contribute to social acceptability to some extent [PSM+16; KG16]. Hence, we have to acknowledge that the visual appearance of the device itself cannot be neglected, and would have to be considered in a future iteration of the HCD process. With our work, we provide the necessary groundwork for these efforts. Prototypes such as PrivacEye, should not be viewed as finished products, but rather as explorations that provide seminal insights for the creation of future product designs. We understand our work as starting point, as the "missing link" between empirical requirement analysis and product design.

5.3.2 Implications

Prototypes fulfill different roles and purposes [HH97; LST08]. In this chapter we exemplified how prototypes can serve to evolve recommendations from empirical research and ideas from design sessions into concrete implementations. We presented a range of prototypes that explore candid design strategies and provide a basis for future product development, most notably, PrivacEye. The prototypes used throughout this thesis were successful in 1) fostering discussions and communicating ides (c.f., Section 4.3), 2) exploring technological opportunities for candid mechanisms (c.f., Section 5.1) and proactive device behavior (c.f., Section 5.2.4), and 3) eliciting first user feedback (c.f., Section 5.2.5). In summary, we were able to exemplify that prototyping efforts can fundamentally contribute to the propagation of user and bystander needs into product ideas. We conclude that a dedicated *Prototype* phase is essential for considering social acceptability issues holistically in a design process. Nevertheless, we note the knowledge gap concerning the effect of different prototyping techniques on user studies, and the performance of (candid) mixed-fidelity prototypes in field evaluations. We address this gap subsequently, in Chapter 6.

6 Evaluating Social Acceptability

Testing interface technologies "in-the-wild", outside of controlled laboratory environments, has become a central element to HCI [MMR+11; WW17]. Simultaneously, as field trials are costly in terms of time and effort, the debate of where exactly they are "worth the hassle" has been going on over the last fifteen years [HN12; KSA+04; KS14; NOP+06; RCT+07]. Nevertheless, there seems to be an agreement that where *social use situations* are concerned, field research allows to uncover user behavior or needs that are not present in the lab [HN12; MMR+11; RCT+07]. In addition there is evidence, that the presence of an experimenter during public device interaction can significantly distort interaction rates and styles [WW17]. With this in mind, it is surprising that research on *social acceptability* is mostly based on laboratory studies or controlled field settings with the experimenter present (see Section 2.2).

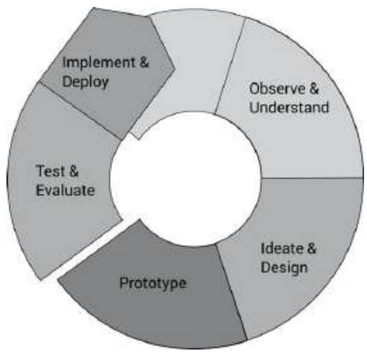


Figure 6.1: Human-centered Design Process. This chapter addresses *Test & Evaluate* and *Implement & Deploy*.

In this chapter, we are taking our research prototypes into the real world (Section 6.1), and investigate real-world user behavior outside of experimental contexts (Section 6.2). The former study, a field survey with a body-worn camera with a screen-based status indicator, allows conclusions about the suitability of the "display camera image" design strategy. We provide evidence that while the design strategy is positively noted for increasing transparency, and employed in state-of-the-art devices [Con16], it may not be effectual enough in practice due to a lack of instant recognition. We furthermore identify prototype fidelity and perceived utility as influential on measured social acceptability and discuss their methodical implications. With the second study, an online survey, we investigate whether lifelogging camera wearers hide or camouflage their devices and how their usage behavior is influenced by social context. Our investigation shows that a large majority prefers to wear their devices openly instead of covertly. These findings confirm that candid design strategies, as explored throughout this thesis, align well with existing usage practices and user needs.

From a methodical perspective, this chapter addresses HCD's *Test & Evaluate* phases, and overlaps into the*Implement & Deploy* phase. Both presented studies address the aforementioned methodical gap, where social acceptability is only sparsely evaluated outside of controlled experiments (c.f., Section 2.2). By conducting a field survey with elements of paratyping (c.f., Iachello et al. [ITA+06]) and reflecting on the employed method we contribute to closing this gap (Section 4.1). Moreover, the investigation of existing usage practices, namely wearing styles of off-the-shelf lifelogging cameras (Section 6.2), is essential to understanding the social context in which novel devices would be used. However, this kind of ethnographic research is also sparsely employed in the context of social acceptability. Thus, the online survey not only concludes our exemplary HCD process by verifying the suitability of candid design strategies in real-life context, but can also be understood as an observational study. Viewed as part of the *Observe & Understand* phase, our results can initiate a new HCD iteration, and motivate further activities towards designing socially acceptable body worn cameras.

6.1 Studying Social Acceptability in-the-Wild

One reason for controversy, discomfort and social tension caused by body-worn "always-on" cameras is that their form factors hinder bystanders to infer whether they are "in the frame". In Section 4.3, we explored design strategies for status indicators for body-worn cameras based on 8 low-fidelity artifacts originated from co-design sessions. Four of these artifacts proposed to display the camera image (or a derived abstraction) as status indicator, which was rated by experts as well understandable and intuitive, but not tested in-the-wild. Simultaneously, best practices for evaluating social acceptability in field studies are rare (c.f., Section 2.2). This work contributes to closing both gaps. First, we contribute results of an in-the-wild evaluation of a screen-based status indicator testing the suitability of the "displayed camera image" design strategy. Second, we discuss methodical implications for evaluating social acceptability in the field, and cover lessons learned from collecting hypersubjective self-reports. We provide a self-critical, in-depth discussion of our field experiment, including study-related behavior patterns, and prototype fidelity. Our work may serve as a reference for field studies evaluating social acceptability.

6.1.1 Contributions and Related Work

The social acceptability of an interface commonly includes two perspectives: the user, and the observer (or bystander) [MAM+10]. Body-worn cameras cause that the observer – being in-view of the camera – also becomes the observed. In addition, contemporary body-worn cameras often do not sufficiently indicate whether they are "ON" or "OFF", and who is within their field of view. A lack of notice may result in a lack of situation awareness on the bystanders' side, and a lack of justification on the user's side (c.f., Section 4.3). A potential remedy is to announce information about the device and its field of view to bystanders by displaying the camera's image; a strategy which is utilized by body cams used for policing, but has not yet been evaluated in a broader context. In this work, we investigate the potential of screen-based status indicators for casual usage based on a collection of 79 diary entries. Each of the nine study participants wore the MirrorCam prototype (depicted in Figure 6.2), for two subsequent days in their

Figure 6.2: The MirrorCam prototype is a chest-worn camera including a screen-based status indicator. We contribute our experiences from an in-the-wild study where participants tested the prototype in their everyday lives and collected 79 hypersubjective impressions in their pen-and-paper diaries.

everyday life, collecting self-reported, hypersubjective impressions and bystander feedback. We discuss and analyze both, experiment and outcome, and provide practical, methodical implications for evaluating social acceptability in the field.

Candid and Revealed Interactions

While mobile and wearable computing mostly aimed to design interactions with devices and interfaces as unobtrusive or inconspicuous as possible, some approaches advocate more "candid" interactions [EGA+15]. Such candid, i.e., revealed or amplified, interactions leverage situation awareness on the observer's side by explicitly pointing out core motives (e.g., application type or purpose) of the interaction with a device. In an early work, Bellotti and Sellen [BS93] employed this principle to provide bystanders with information about a stationary camera; from a display mounted next to the camera the bystanders could obtain feedback about the captured imagery, whether they are in range and how they look like. This "Confidence Monitor" is described as trustworthy, meaningful and appropriately timed, but – being stationary – was not transferred to wearable computing devices. Utilizing (additional) displays to achieve this kind of transparency (or "candidness") for wearables has mainly been explored in the context of virtual reality. To reveal social signals and leverage communication between the headset's user and bystanders, researchers proposed to augment Virtual Reality headsets


Figure 6.3: During the two-day field test, our participants wore the MirrorCam prototype in various locations and situations, such as public transport (left), and university (right).

with one or more screens facing the bystander. These might overlay the user's occluded eye-movements [CM17], or the virtual environment (s)he is in [CM17; GSS+18], or let bystanders "see-through" the headset by displaying 3-dimensional renderings of the user's face [GSS+18].

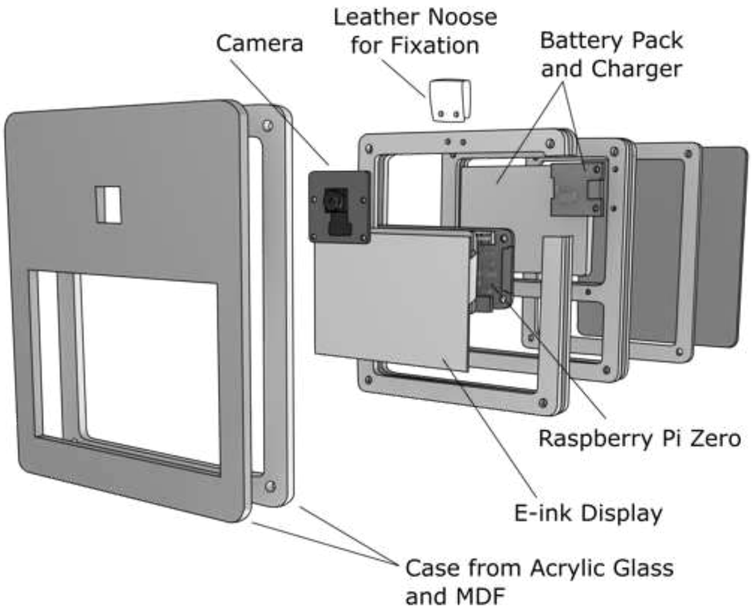
Contributions

We contribute a discussion of methodical implications for evaluating social acceptability in the field, based on a diary study testing the "displayed camera image" design strategy. In particular, we cover lessons learned from collecting hypersubjective self-reports using diary studies, problems arising from prototype fidelity, and issues with study-induced user behavior. What we intentionally, and unintentionally learned from the presented experiment may serve as reference for other researchers conducting studies on social acceptability in the field.

6.1.2 Apparatus and Method

Diary studies are beneficial to gather insights about technology phenomena in uncontrolled, in-the-wild settings, and limit the impact of retrospectice interpretation [LHF17]. Using a dedicated prototype as research vehicle, we conducted two day field trials ("diary study", Figure 6.3), where the participants noted down their experiences in a pen-and-paper diary.

Prototype. Most notably, our medium fidelity research vehicle, a custom-build chest-worn camera, features a a 2.7" eInk display. In contrast to a colored LCD or TFT display, this allows for a wider viewing angle, and lower power consumption. In addition, it is less prone to reflections caused by sunlight, and provides a slight abstraction, which has been hypothesized to increase trustworthiness (see Section 4.3). The use of a custom-build prototype allowed to rule-out brand specific effects, however, at the cost of increased size (see also Section 5.1). We provide all technical details in Figure 6.4.



Processing Unit: Raspberry Pi Zero v1.3 including camera module v2.1 with a resolution of 1080p@30 fps. A 2000mAh battery pack, and a 3.7V to 5V converter module provide it with power supply for approx. 6h.

Display: PaPiRus driver board with a 2.7" eInk/ePaper screen; screen resolution: 264 x 176 pixels, screen size: 60mm x 40mm. In contrast to a colored LCD or TFT display, this allows for a wider viewing angle, lower power consumption, and is less prone to sunlight reflection.

Case: the 90mm x 105mm x 33mm case is composed of 3mm acrylic glass, and 3mm medium-density fiberboard (MDF) using a sandwich technique. Layers are fastened with M2.5 screws, a leather noose is screwed to the top delimiter for safe fixation to a lanyard.

Figure 6.4: Technical details of the MirrorCam prototype. Cables and connectors omitted for visual clarity.

Enrollment and Study Procedure

We recruited our participants on campus, as students – in contrast to professionals – are more mobile during a typical work day. This allowed to maximize the variety of locations and situations explored during the study, while minimizing the time effort for each participant. They registered for a period of four consecutive days, with intervals being spread out to cover all weekdays, including weekends. Following the the recommendations by Hoyle et al. [HIC+15], each participant registered for a one-on-one enrollment slot, where they were briefed about study purpose and discussed a list of Do's and Dont's with the experimenter. After providing informed consent, they received the study equipment (c.f. Figure 6.5). 30 min briefing session (Day 1), a two days field trial (Days 2+3), and a 30 min debriefing session (Day 4). During the field trial the participants were asked to wear the MirrorCam prototype whenever possible, for about 2-6h per day. They were asked to wear the prototype in a way that its screen was observable by those around, explain the purpose of study and device to persons in their vicinity, and collect their reactions in the diary. They also received a set of information cards to be handed out to third-parties inquiring about the study (including a link to FAQs). In contrast to [HTA+14] our prototype did not persistently store (image) data, and did not require in-situ delete.

Ethics

Following recommendations for studies with wearable cameras [HIC+15], we provided each participant with information cards to be handed out to third-parties inquiring about the study (including a link to a website with FAQs), as well as a list of Do's and Dont's that was also discussed in the one-on-one briefing session. In contrast to [HTA+14] our prototype did not persistently store (image) data. Thus, we did not require an option for in-situ delete. Nevertheless, participants were asked to pause the study whenever they felt the presence of a camera to be inappropriate, or people around them express discomfort with the device. In these cases they should turn the MirrorCam Prototype off and put it away, as wearing the device in idle/turned off state might cause irritation and bias. Participants were told that they should let others know that the MirrorCam Prototype does not store any pictures persistently and does not record audio. This procedure was approved by our institute's review board. Each participant received a 20€ Amazon voucher.

Data Collection and Analysis

We collected demographic information, as well as prior experiences with body-worn cameras during the Day 1 briefing session. During the field trial (Days 2 and 3), the participants wrote down their impressions as well as bystander's reactions into their diary. Each diary page contained a 5-pt Kunin Scale [Kun55], and space for a free-text explanatory statement, as depicted in Figure 6.6. The explanatory

Figure 6.5: Study equipment, including MirrorCam prototype, charger, an A7 journal (“diary”), and a set of information cards.

statements could include the participant's relationship to the feedback provider (e.g., fellow student), and the location if they felt it was relevant to the situation. They were asked to omit any identifying information (e.g., names, study modules or room numbers). After the field trial, the participants were re-invited to the lab (Day 4) for a semi-structured interview, where they discussed their overall experience. In addition, they were asked to point out diary entries that they found noteworthy, surprising, or most relevant. The interview was audio-recorded. Both, diary entries and interviews, were transcribed, digitized and qualitatively analyzed using inductive category development [May14]. In their diaries, our participants not only report individual views, but also feedback and reactions they witnessed during the field trial: the collected qualitative data is not only subjective, but hypersubjective. Thus, we count themes (denoted as n) based on the number of diary entries (N=79), and denote participants as P, diary entries in `verbatim`, and interview excerpts in *italic*.

6.1.3 Results

Nine participants (4f, 5m), aged 22 - 30 (M=26, SD=2) collected N=79 distinct diary entries, recording between 2 and 18 (M=9, SD=6) entries each. They showed surprise to having received mostly neutral (Mdn=3, SD=1) feedback. One fourth of the diary entries report expectations of a (positive or negative) reaction, where the participants did not perceive any (no reaction, n=20). P4 puts down: "`Quick glances (at most)`", which resonates with the other participants' self-reports during debriefing: "*even when I was roaming university campus*" (P7). Subsequently, we detail on the perception of the device and screen, the participants' self-perception, and study-related behavior patterns.

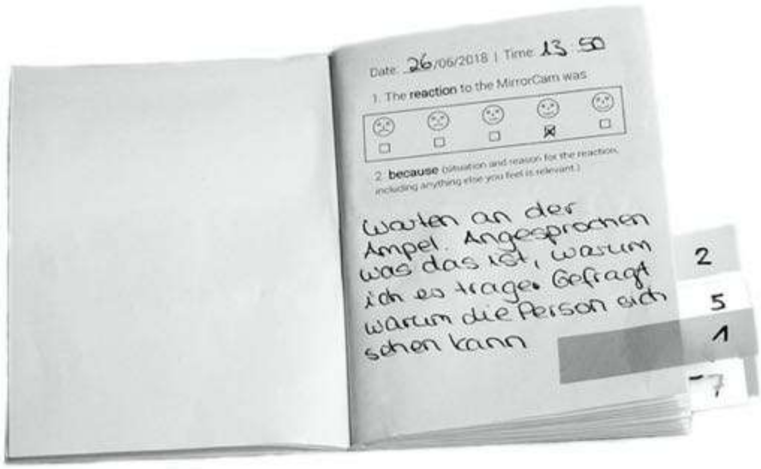
Wearing a Camera in Public

Many bystanders displayed curiosity and interest (n=17). However, multiple entries also report avoidance behavior (n=6) and skepticism (n=9). In particular, participants reported that "recording" in terms of persistent data storage was key: "*[I told him] it doesn't record,[...] then he was like ok, then it is somehow interesting; tell me more. Why do you do this [...] there is no use if it does not store anything*" (P4). These show the relevance of the persistence of recorded imagery to social constraints (recording matters, n=8). On the other hand, diary entries also showed evidence of a perceived culture of surveillance: "`I'm under surveillance anyway`" (P3).

(Mis-)interpreting the Screen

The integrated screen was noted positively for increasing transparency (n=3), and sparking conversations. Explicitly positive reactions (n=5), such as bystanders referring to the device as "cool" or "funny", and waiving at it were also noted:

(a) Participants collected their impressions in a A7 diary. During the debriefing interview selected diary entries were discussed, marked and numbered for reference (page markers).



(b) Each page consisted of fields for date and time, a 5-pt Kunin Scale: *"The reaction to the MirrorCam was..."*, and space for a free-text explanation, including the (given) reason for the reaction and situation: *"because... (situation and reason for the reaction, including anything else you feel is relevant.)"*.

Figure 6.6: Pen-and-paper journal used by the participants to record their impressions during Days 2 and 3 of the study.

"[They] stood in front of it and waved [at it]. So like 'Hey what's that? Hey I can see myself'" (P6). Only twelve entries report bystanders recognizing themselves in the integrated screen (recognition, n=12), but rather that the prototype was misinterpreted, e.g., as game or jewelry, and not being recognized as camera (interpretation, n=7). Two participants (P3, P5) observed that bystanders understood the prototype as assistive technology and attributed this to its single piece appearance, and medium fidelity (c.f., Excerpt 1).

Self-perception of the Participants

Though mostly targeting bystander reactions, many entries reflect the participants' self-perception. The felt observed or looked at, even without any explicit reaction to the prototype (perceived attention, n=13). P7 questions their objectivity "*So I guess there was a discrepancy between my perception and how it actually was, because I think people didn't actually look at me , but I always made sure whether anyone was looking at me. So I actually felt looked at; [I] observed whether someone around feels uncomfortable, or someone gawked at me [...]* ". In addition, participants stated to have enrolled in the study to test their self-confidence; Some expressing surprise about their reluctance during the study (c.f., Excerpts 2 and 3). P8 recalls *"I had difficulties on the first day and also a little bit on the second day to find any situations where I felt comfortable using [the wearable camera]"* (P8).

Study-related Behavior Patterns

As previously noted, our participants had expected more negative reactions to them wearing a camera, and some of them viewed their study participation as a self-test (c.f., Excerpt 2). From the interviews and diary entries, we observed a number of correlated behavior patterns. As illustrated by Excerpt 4, three participants explicitly sought bystander feedback to achieve a high number of diary entries. They reported to have chosen clothing, locations and/or body postures that highlighted them wearing the device. In contrast, as also reflected by the number of entries' high inter-subject variance, others wore the prototype only where they felt confident to not trigger concerns. In addition to the study's Do's and Dont's[1], some participants took additional measures to not be accused of surreptitious picture-taking: P4 emailed their colleagues about their study participation, and P6 acquired consent from a supermarket's branch manager before entering the store.

[1] The list of Do's and Dont's, based on [HTA⁺14], is included in Appendix E.

Excerpt 1: Interpreting the prototype as assistive technology.
He also said, that his first impression was somehow as if I had some handicap, and that it [the prototype] was a support for it. Maybe in a way that it records what I see here and then somehow gives me an input. I think that's why people tended to look so nervous and embarrassed at me.

-P3

Excerpt 2: Study participation as a test of self-confidence.
I have to say that I found it surprisingly difficult to wear the thing, not because it was uncomfortable or so, but because it has cost me quite some effort to take with me in social situations. I had expected this a little, that's why I found the study so exciting, because I thought, ok, I wanted to test myself, too. [..] I also react to other people wearing cameras [..] a situation that I do not find so pleasant. So it was definitely fascinating.

-P4

Excerpt 3: Feeling comfortable by avoiding conflicts.
I had difficulties on the first day and also a little bit on the second day to find any situations where I felt comfortable using [the wearable camera].

-P8

Excerpt 4: Provoking bystander feedback.
At the beginning I felt a bit weird, so when I went out for the first time I thought, hm, usually no one really looks at me [..] so I just wore a black T-shirt, where I thought I'd feel a bit comfortable with [the black camera]. Then, I went for a short round outside, ran a few errands, and then I put on a white T-shirt (laughs) and thought, so now I want people to recognize it, because there was not really any content, people have looked somehow, but no one had reacted [to the camera]. [...] At first, I have also been wearing my hair down, then I made a pony tail, in order to present it [the camera] more, because I wanted to have some feedback [..] so a bit more provocative.

-P6

6.1.4 Discussion

In the following, we discuss both, our diary study's results, and methodical implications of evaluating a research prototype's social acceptability in the field.

Value and Limitations of Diary Studies

Diary studies (contrary to observations, or lab experiments) induce typical limitations (c.f., Lazar et al. [LHF17]): participants may not follow through, and only sparsely record entries, plus recruitment is more slow-going as with a less intrusive study (e.g., a survey). In addition, self-selection bias can occur, as volunteers likely have greater technology affinity than average. However, this is not unrealistic: tech-savvy audiences are also more likely to become early adopters, and thus, encounter similar reactions in public as our participants did. Moreover, our study design anticipates, and partially mitigates effects of self-selection bias due to the hypersubjective nature of the reports: participants also recorded how they were perceived by others. Such (hyper)subjective reports from diary studies as ours can provide valuable insights on social effects of technology, but, being subjective, have to be taken with care.

Mitigating Study-related Behavior

Our work illustrates effects of study-related behavior: While avoidance of (negative) reactions is likely to reflect real usage patterns, some participants might feel the need to provoke as many reactions, i.e., diary entries as possible. These might be biased or unrealistic. A remedy might be to record the nature of the participants' behavior and encounters: were they acting outgoing, reserved, or provocative? Was this behavior characteristic or atypical for themselves? What was their relationship to the bystander(s)? Hence, in addition to the measures taken in our study, careful one-on-one briefing, oral explanation of the diary entries, and equal pay for all participants, future work should further contextualize the participant's self-reports to account for potential effects from study-related behavior.

Recording vs. not Recording

For ethicality, our prototype did not persistently store image data, which raised questions about the "value" for the participants: why would they wear such a device, if they do not get to keep the images? This might be problematic, as perceived utility (c.f., Profita et al. [PAF+16]) can influence social acceptability. Thus, it might be sensible to introduce "added value" (e.g., images to keep, an app or game) for the participants to increase realism in future studies.

On the other hand, our results also indicate that persistently storing, in contrast to "piping-through" imagery, does affect potential privacy concerns, and thus, transitively, social acceptability, which has implications for technologies using a camera as sensors, e.g., image-based tracking. Work on status indicators would thus not only aim to communicate what data is captured, but also what for (c.f., Section 4.3).

Prototype Fidelity

While the MirrorCam prototype was perceived less salient than its size might have suggested, its medium fidelity also had unforeseen effects, as it created the impression of the prototype being an assistive device. As assistive devices tend to be more accepted than consumer “just-for-fun” devices [PAF+16], such “AT-Effects” might bias social acceptability studies with non-consumer devices. Thus, future work should consider to what extent social factors can be evaluated with low-fi prototypes outside of lab environments (where participants “imagine” the final interface).

6.1.5 Summary

We presented results and experiences from a field test of a wearable camera with a screen-based status indicator, which was noted positively for increasing transparency, but not always recognized by bystanders. Our findings furthermore indicate that (1) diary studies are suitable means for evaluating aspects of social acceptability, and collecting hypersubjective impressions, but that (2) studies investigating social acceptability aspects should account for “perceived utility”. Thus, it is advisable to equip the to-be-tested device with an “added value” for the participants. (3) Prototype fidelity may impact on bystanders’ reactions and interpretations. Future work might provide methods and best practices to mitigate such effects in social acceptability studies, e.g., by employing Wizard-of-Oz techniques.

6.2 Usage Habits of Lifelogging Camera Wearers

How a photographer is perceived largely depends on whether she is holding a traditional camera in front of her face or has a miniature camera pinned to her clothes taking pictures every 10 to 30 seconds [WSB+14]. In contrast to traditional cameras, body-worn cameras, such as the Narrative Clip, can also be worn in many different ways, including openly and undisguised to fully concealed or camouflaged as illustrated in Figure 6.7. Utilizing those lifelogging cameras for secret photography might however, be perceived as “creepy” or ethically questionable (c.f., Figure 6.8).

Figure 6.7: Camouflage of lifelogging cameras [Left to right, top to bottom]: unobtrusively attached to an event badge, paired with headphones to be mistaken as audio player, disguised as jewelry, worn on same-color clothing and decorated with stickers and hidden amongst buttons and pins.

6.2.1 Contributions and Related Work

Though still a rare sight, wearable cameras for lifelogging have become increasingly popular among tech-savvy audiences. From their usage habits we can gain unique insights outside of controlled experiment settings. In this work, we investigate whether users of lifelogging cameras prefer to wear them openly or in a concealed, less obtrusive manner. We see our survey as *complementary to prior experients* on the mutual influence of social context and wearable cameras. For instance, Alharbi et al. [ASV+18] evaluated chest-, wrist-, and shoulder-worn cameras in a field study. They looked into the types and sources of discomfort caused by the devices, their impact on the wearer's comfort and behavior, and social presence and stigma. In contrast to our work, their participants were not habitual users of body-worn cameras before the experiment and wore the camera only for structured activities plus additional 2 hours. Other related work, including our own (see Section 6.1), also did not cover experiences from self-motivated device usage: they focus on cultural probe studies and initial reactions from inexperienced participants [HVC+15], or collected bystander feedback with proxies [NMH+09; KWH+19] or actors [DDK14] wearing the device. Views of device owners (as opposed to participants provided with the device) are not covered. To the best of our knowledge we are the first to investigate how social contexts influence usage habits without prior experimental intervention (e.g., by providing a device). The camouflage of lifelogging cameras, specifically the *why (not)* and *how*, has also not been covered by prior work so far.

In this section we investigate the social implications of lifelogging cameras based on how they are used and worn. We discuss two research questions in detail:

R1: *Are lifeloggers hiding their lifelogging cameras?*

R2: *How are usage habits of lifelogging camera wearers influenced by social contexts?*

We provide insights based on a comprehensive online survey (N=117) among users of lifelogging cameras, conclusively answering the first research question (R1). Purposive sampling via social media allowed us to sample real-world experiences and habits from actual device users outside a constrained academic or laboratory setting. Additionally, we present a number of qualitative insights from a user's perspective regarding the effect of socio-environmental relationships on actual usage behavior, thereby contributing to an understanding of the social implications of lifelogging cameras (R2).

Figure 6.8: Anectotal evidence. Users of the “Narrative Clip Lounge” (a public Facebook group) are discussing a particular method of camouflage. [Screenshot taken on 10.04.2017]

6.2.2 Online Survey

In the subsequent section, we go into detail on the questionnaire used in the survey, the method of recruitment, and discuss participants demography as well as potential limitations.

Apparatus and Analysis

The online survey consisted of 6 two-tiered questions (Q1 - Q6) where participants could answer each question through a 5-pt Likert scale (1-never to 5-frequently) as well as a free-text explanation: *If so, please tell us about the occasion(s).*. The questions focused on the frequency of particular events such as being asked to take the camera off. All questions were asked in a neutral, non-judging way. To clearly delineate stashing the camera in one's pocket, we rephrased the term "hide it" to "make the camera less stand out."

Q1 *Others were curious about my lifelogging camera.*

Q2 *Others reacted angrily to me wearing a lifelogging camera.*

Q3 *I have been asked to turn my lifelogging camera off or to take it off.*

Q4 *I have tried to hide or conceal that I was wearing a lifelogging camera.*

Q5 *I try to wear clothes matching the color of my lifelogging camera to make it less stand out.*

Q6 *I use accessories to make my lifelogging camera less stand out.*

We furthermore anticipated bias from social desirability (acquiescence) through additional projective, indirect questions, e.g., whether they knew of other people concealing their lifelogging cameras. In addition, wearing frequency, camera position and demographics were recorded. Qualitative results were analysed using the procedure of inductive category development [May14]. Re-occurring themes were summed up (occurrences denoted as n); duplicate entries by individual participants were removed.

Q7 *Do you know of any other strategies that have been used (either by you or by others) to make lifelogging cameras less stand out? Please explain.*

Recruitment, Demography and Device Ownership

Our survey targeted users of lifeogging cameras, a very specific and not easily accessible user group. To facilitate recruitment, we used Narrative Lounge[2], a Facebook group (2.5k members at the time of evaluation) as the base for purposive

[2] Narrative Lounge, `https://goo.gl/CtEqeH`, accessed 2019

sampling. Responses were collected anonymously, data collection and recruitment method were approved by an internal institutional review process. We recruited 117 participants (96m, 18f, 3d), between the age 19 to 84 (M=42 , SD=13), located in Europe (42%), the US/Canada (30%), and Asia (21%) followed by Oceania (5%). Middle East/North Africa, South/Central America and Africa were represented by one participant each. A large majority of participants indicated a University or college degree (n=77, 69%) or doctorate/postdoctoral lecture qualification (n=10, 8.5%) as highest level of education (ISCED[3] level 6 and above). Twenty-four participants (21%) had obtained a High School Diploma or Associate degree (level 5), and overall 6 participants indicated ISCED levels 4 or below. Participants were asked for the kind and brand of lifelogging camera they owned (multiple selections possible). Since we used the Narrative Clip Lounge Facebook group for recruitment, the majority (116, 99%) of participants owned a Narrative Clip generation 1 or 2. Participants however, also owned other devices including the Autographer (4%), 61N (1%), YoCam (1%), iOn Snap-Cam (2%), meCam Classic (2%), SnapChat Spectacles (1%), and Perfect Memory (1%). With the exception of the SnapChat Spectacles, all those devices share a common form factor; a rectangular, square or circle shape with a diameter between 1 and 2 inches that provides various ways of being attached. Reported usage frequencies (c.f., Figure 6.9) were widely spread, with 31% of the participants using their device at least once a week. Participants were not provided an incentive for taking part in the study.

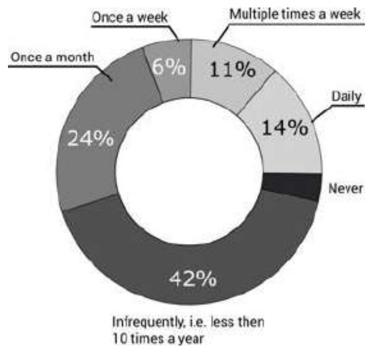


Figure 6.9: Usage frequency as indicated by the participants (N=117). Four (3%, “Never”) did not use their device (anymore) at the time of evaluation.

Limitations

With 5% response rate of the sample (members of the “Narrative Lounge”), results are likely to be representative for the group’s members assuming a non-systematic non-response bias. However, the sample as well as the user group “lifelogging camera wearers” might be inherently biased through an over-proportionate number of typical early adopters, i.e., males with above average income and education. Thus, the results might not be generalizable to the population at large, which would affect our results’ future applicability if lifelogging cameras were to become broadly adopted. Moreover, since the survey did not cover the bystander’s point of view, some aspects of wearable cameras in a social context might have been missed. The sampling procedure, while providing access to users with long-term real-life

[3] International Standard Classification of Education (ISCED), `http://uis.unesco.org/en/isced-mappings`, accessed 2019

experiences, also induced a bias towards Narrative Clip users. As a large number of lifelogging cameras share the Narrative Clip's form factor, including size and available attachment methods, we believe that the results regarding wearing styles are to a large extend transferable to other, similar devices. Nevertheless, devices with a substantially different form factor, such as wrist- or head-worn cameras might induce different usage habits. Regardless, we believe that the discussed usage habits in social contexts might also apply to other body-worn cameras.

6.2.3 Results and Discussion

In this section we summarize and discuss the online survey's results and highlight key findings and core motives.

Where and how to wear?

The majority of participants (58%) indicated that they wore the camera on their lapels. They also chose to wear it at the pocket of a jacket/shirt/blouse (n=38, 33%), in the center of the collar (32%) or as a necklace (30%), as visualized in Figure 6.10. While it is also popular to clip the lifelogging camera to a messenger bag or handbag (17%) or to the straps of a backpack (20%), options such as clipped to the waistband/belt (3%) or pocket (4%) of trousers, jeans or skirts were selected rarely. Participants considered those variants to be less obtrusive (n=3), as they were outside an observer's line of sight. However, positioning the camera below the waistline also affects the field of view, which was named as one reason for choosing their wearing position (*point-of-view*, n=47). This also implies that current form factors might be reconsidered to allow wearing positions closer to the human POV, as suggested by Wolf et al. [WAS$^+$15], who found that images from a head-worn lifelogging camera are perceived to produce the most relevant and most desired imagery. However, as the participants further named *convenience* (n=23) and *unobtrusiveness* (n=14) as decision criteria, a head-worn lifelogging camera (e.g., 3RDi Third eye[4]) might face acceptability issues.

Ice-breaker or offending object?

While 105 participants (90%) reported others being curious about their lifelogging camera (Q1, $Mdn = 3$, $SD = 1.3$), participants also had the impression that their lifelogging camera was usually not noticed (n=7) or noticed but not identified as a camera (*unknown object*, n=23). P58 states: *"I am surprised how few people ask about it. Maybe once a week or so someone asks me what the white square on my lapel is"*. Participants reported lifelogging cameras to be mistaken as jewellery (n=4) or confused with a walk-distance meter (P87). This can be explained by the novelty of the device type as well as the lack of visible affordance: *"It is not*

[4] `http://www.3rditek.com/`, accessed 2019

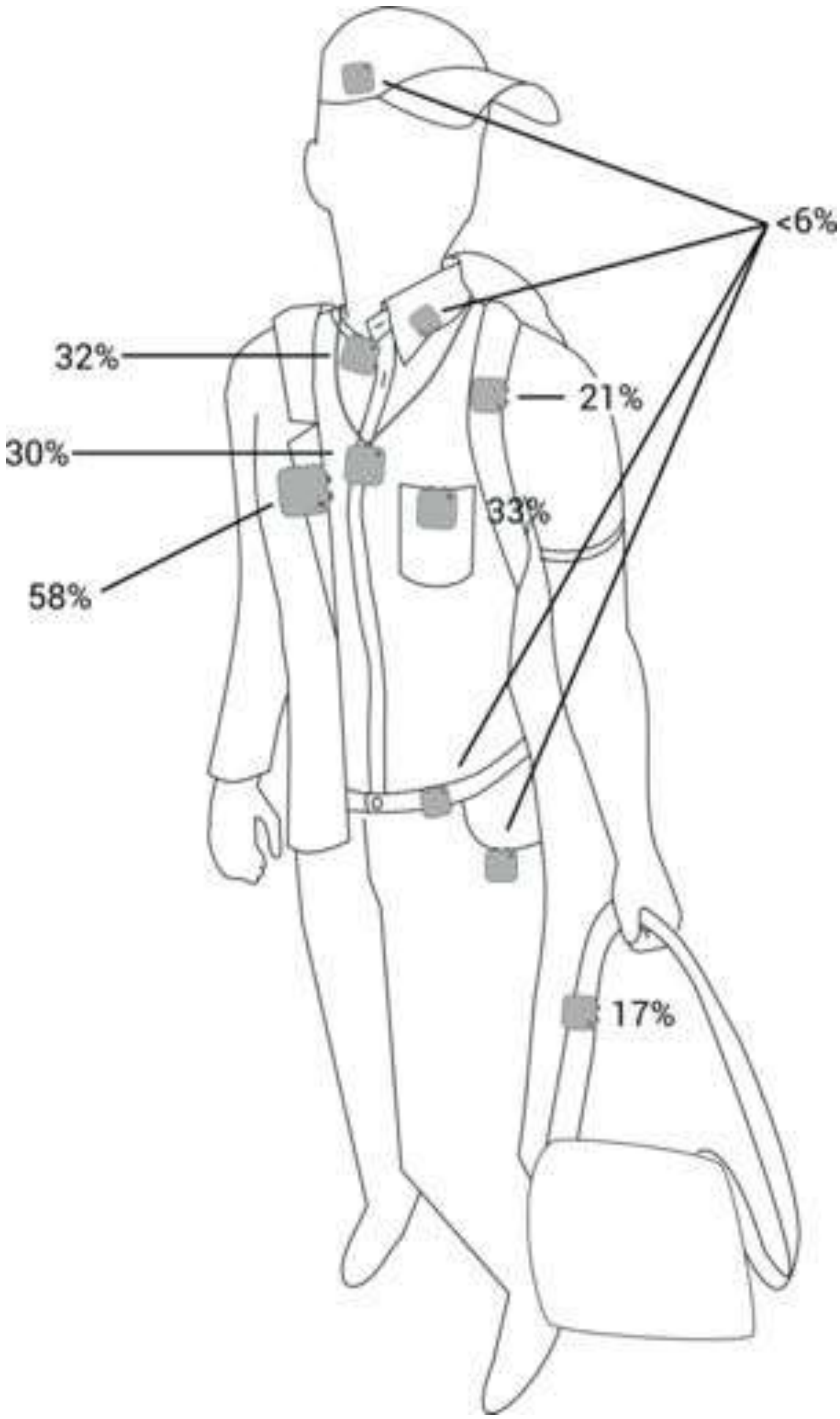


Figure 6.10: Most frequently chosen wearing positions: by the lapels, at the pocket of a jacket/shirt/blouse, in the center of the collar, as a necklace, clipped the straps of a backpack, or to a messenger or handbag. Multiple selections possible.

obvious what this thing is doing" (P21). There is an ongoing debate, whether the lack of visible affordances increases (c.f. Rekimoto [Rek01]) or decreases social acceptability, as suggested by Ens et al. [EGA+15] and our own prior work [KKM15]. A minority of participants (29%) had ever experienced angry reactions (Q2, Mdn=1, SD=0.7), and 35 participants (30%) have been asked at least once to take it off (Q3, Mdn=1, SD=0.8). Requests to remove the camera have been reported for a broad spectrum of contexts, including *personal* (n=11), *public* (n=5), and *professional* (n=5) occasions. With no (monotonic) correlation between usage frequency (Figure 6.9) and observed answers ($r_S(115) = 0.08$, $p > .05$), usage frequency seems to not affect the likelihood of experiencing angry reactions. Daily users of lifelogging cameras might, however, have grown accustomed to e.g. accusing looks, and thus become less sensitive to implicit negative, or angry reactions, as inquired in Q2. Experiencing reticent disapproval such as angry looks (non-verbal disapproval, n=7) has been reported by a small number of participants. Consequently, these participants either took down the device (n=5), or ignored the looks (n=2). *"I was never directly asked to take the camera off, but people's discomfort often made me take it off of my own accord"* (P42). Similarly, other participants witnessed perceptible unease (n=13) of peers and by-passers. They furthermore reported their peers to have verbalised concerns such as whether (their) permission was required for the recording (*permission*, n=7), whether and where recorded imagery would be stored, processed, used or shared to (*purpose*, n=5), as also discussed by Denning et al. [DDK14].

Two participants reported having experienced explicit *avoidance behaviour* by friends and family when wearing their lifelogging device. Explicitly negative reactions were reported by nine participants. Contrarily, several participants reported that their lifelogging camera functioned as a conversation starter or ice-breaker (n=10). P14 explains *"I'm an IT consultant, so often wear clip at conferences. Great way to connect with fellow nerds"*. Participants also reported experiencing explicit positive reactions (n=11), such as acquaintances making *"funny faces"* (P19), or greeting and acknowledging the device and its wearer: *"When I wear it to school, students notice right away and smile and wave at it/me"* (P25). This evidence implies that lifelogging cameras might both foster social interaction with loose contacts, but also prevent more personal or intimate interactions with relatives and friends; However, this is to be confirmed by future research.

Hide it, highlight it, or just blend in?

When asked whether they ever attempted to hide their lifelogging camera, 53 participants admitted to doing so at least occasionally, while a small majority of participants stated to never hide it (Q4, 64, 55%, c.f. Figure 6.11). Apart from avoiding negative reactions (*anticipated objections*, n=12), and undesired attention (n=7), authenticity (n=10) was named as the prominent reason for camouflaging lifelogging cameras: *"So that people appear to be in their natural*

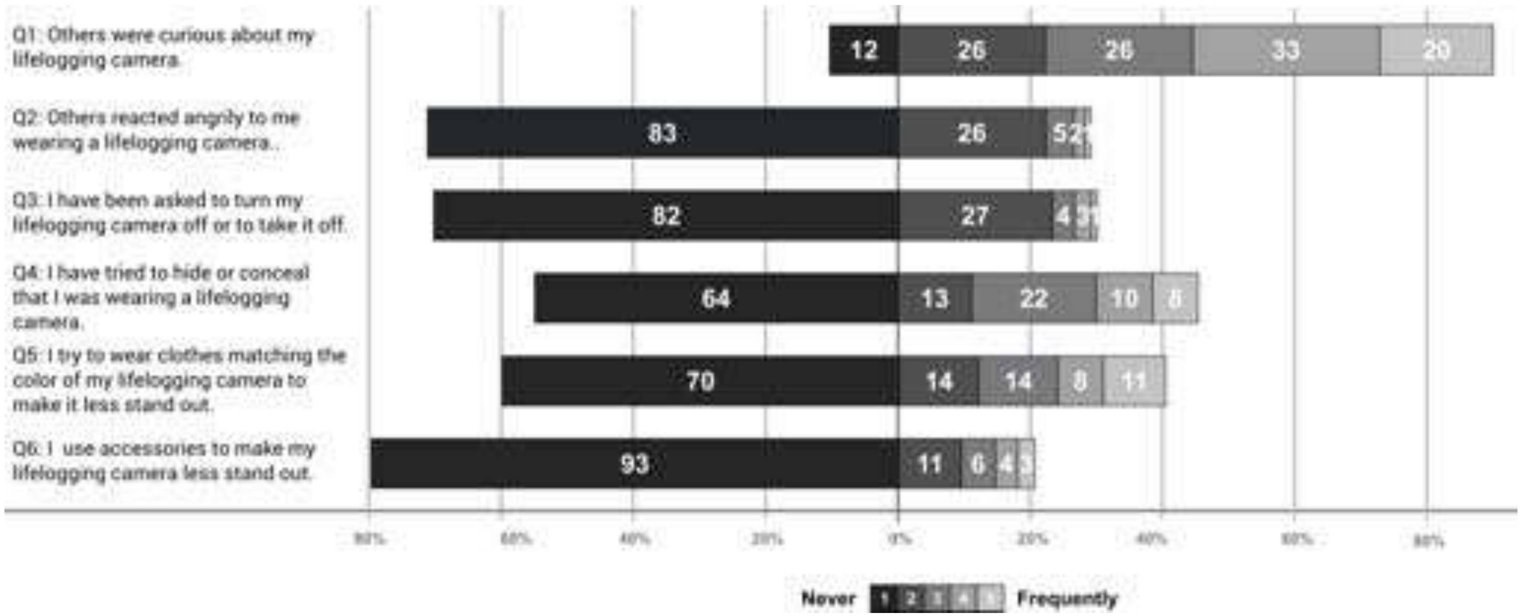


Figure 6.11: Detailed results of Q1 - Q6; based on 5-pt Likert scales ranging from 1 (*never*) to 5 (*frequently*).

state if they do not know the existence of a camera" (P27). Among other strategies (c.f., Figure 6.2), wearing clothes matching the camera's color was reported as well-known obfuscation method, however rarely used in practice (Q5, Mdn=1, SD=1,4). Instead, some participants just tried to not call attention to the device even though it was worn in the open (*blending in*, n=11). P25 stated *"I don't hide the camera. I rarely point out that I'm wearing one, though"*. In contrast, other participants (*justification*, n=5) purposely highlighted their life logging device. P113 remarked, *"I actually try to make it stand out, not be accused of 'secretly filming' others"* (P113). This interesting strategy is backed by a prior study where participants described recording from AR glasses as different and potentially less acceptable as other types of recordings as it was more subtle [DDK14]. Moreover, several participants stressed that it was unethical to hide the camera (*ethical concerns*, n=6).

Between Circumventing Regulations and Self-Censorship

Some locations (e.g., museums) typically bar photography. These restrictions usually apply to all types of imaging devices, including traditional analogue cameras, digital cameras, camera phones and body-worn cameras. Unsurprisingly, participants reported that they were required to take off their life logging camera at those places (*no-camera rules*, n=12). Several also stated that they had deliberately used their lifelogging camera to outsmart no-photography rules (*circumvent regulations*, n=8), and some even admitted to concealing the truth about their device when asked. P90 explained *"Once I told airport security that it was jewelry and the answer was not questioned – but I felt justified since airports have their own cameras"*. This attitude is explained best by the concept of *Equiveillance*, which advocates the individual's right to record his or her environment while being recorded himself/herself [Man16]. On the other hand, a large number of participants employed some form of self-censorship (n=9), i.e., to use their lifelogging camera only at locations or events where they perceived it as appropriate and permitted. *"When meeting people (e.g., at work, for a beer) in situations where only a few people are present I usually take off the camera without being asked"* (P90). This corresponds to behavior observed in the context of mobile gestural interaction [RB10a], where the perceived "appropriateness" as well as the users willingness to interact depends on location and context. This self-controlling behavior might be a successful measure to prevent angry reactions or requests to remove the device. Elaborating on Q3 (*"I have been asked to turn my lifelogging camera off or to take it off"*), P113 responded *"Never. I know where I can use it or not"*. This aligns well with prior work, where lifeloggers were found to actively ensure the privacy of bystanders [HTA+14].

6.2.4 Summary

In this section, we presented results of an online survey (N=117) investigating real-life usage habits of lifelogging camera wearers. Our empirically backed analysis shows that (A) most lifelogging camera wearers prefer their camera to be noticeable by bystanders, as (B) wearing a lifelogging camera in a too unobtrusive or concealed fashion might be considered unethical. Furthermore, some tend to explicitly highlight their camera, in order to communicate outright that they are wearing a camera, and (C) employ self-censorship to comply with what they perceive as ethically and socially acceptable usage behavior. In conclusion, body-worn cameras face an an interesting dichotomy: On one hand they pose a threat to personal privacy as well as corporate confidentiality by facilitating secret, unpermitted photography, on the other hand lifeloggers often take explicit measures to protect bystander privacy and lifelogging cameras can sometimes even foster interactions by playing the role of a conversation opener. Our future research will extend the current investigation by surveying demands of potential bystanders. This will allow to generate design recommendations involving both, the wearer's and the bystander's perspective. With hardware manufacturers building increasingly smaller sensors, this will be one crucial aspect, as designers of body-worn cameras will have to decide on form factors that balance unobtrusiveness and noticeability, as well as visual appeal.

6.3 Summary and Conclusion

This chapter addresses HCD's *Test & Evaluate* and *Implement & Deploy* phases. The first study (Section 6.1) continues design suggestions from our co-design sessions (Section 4.3) that we implemented into a concrete prototype (Section 5.1), a body-worn camera with an integrated screen-based status indicator. We evaluated the device in a field survey, where nine participants wore the device for two days in unconstrained, everyday settings and documented their experience in overall 79 diary entries. Our study provides evidence, that the interpretability of screen-based status indicators is not optimal. Nevertheless, if explained, the status indicator as such, was recognized for increasing transparency and bystander awareness. This aligns well with the findings from our second study (Section 6.2), where we found wearers of lifelogging cameras to prefer candid instead of hidden wearing styles, but also identified a lack of visible affordances. In the following, we detail on limitations and generalizability.

6.3.1 Limitations and Generalizability

Both studies presented in this chapter follow a use case agnostic approach. As a result, findings from both studies are applicable to a large variety of use cases involving body-worn cameras, including different contexts and environments (Section 6.1), intentions and wearing styles (Section 6.2). However, this openness also comes at the cost of inherent limitations, as it neglects “perceived utility” which depends on the concrete use case. As unearthed during our field survey (Section 6.1), such “perceived utility” may impact on bystanders’ reactions and interpretations and in consequence affect the user’s ability to justify device usage (c.f., Section 4.3, *justification*). In consequence, aspects of social acceptability directly related to the device’s (assumed or actual) purpose were less salient than they would have been if we explicitly evaluated assistive versus more superfluous uses (c.f., Profita et al. [PAF+16]). Due to the original focus of this thesis – design features (e.g., status indicators) that shape social acceptability – we explicitly decided to not retroactively include one or two concrete assistive use cases. From our perspective this is crucial, as the only way to responsibly implement such an application would have been to include the respective user group (e.g., visually impaired persons) in all development phases, i.e., during *Observe & Understand* and *Ideate & Design* (c.f., Erard [Era17]). Nevertheless, we believe that the exploration of assistive uses of socially acceptable body-worn cameras that show in a sensible way what their purpose is, is worth exploring – participatorily – in future work.

For the studies presented in this chapter, we opted for uncontrolled settings to maximize ecological validity; namely the field deployment of a functional prototype and a large-scale exploration of the circumstances under which off-the-shelf wearable cameras are already used. While this approach allowed to broaden the method palette (c.f., Section 2.2), it also increased the risk of introducing confounds, e.g., from self-selective recruitment. To address these shortcomings we included a discussion of study-related behavior patterns and suggested mitigation strategies (c.f., Section 6.1). We furthermore outlined potential bias from interviewing early adopters. While early adopters can share valuable first insights, it is indeed crucial to mind that early adopters are likely to have less reservations and more affinity towards technology than “the general public” and that their views might differ; specifically on aspects relevant to social acceptability such as perceived harms (costs) and benefits (c.f., Eghtebas et al. [EPV+17]). Nevertheless, studies involving early adopters also overcome the issues of “imagined use” and artificial, too confined lab settings, and hence provides a fresh perspective on real-world usage (c.f., Section 2.2). Notably, both our studies provide empirical evidence that camera wearers (i.e., early adopters) perceive deliberate concealment as unethical, and that moderate noticeability is favored – a notion that is shared also by non-users and potential bystanders [ECK17; KB19] and therefore likely generalizes.

6.3.2 Outlook

The work we presented in this chapter supports findings from prior work and might equally motivate future work and system development. Our field survey confirms earlier results, where Alharbi et al. [ASV+18] found camera wearers to report more concerns about bystander privacy than bystanders themselves. We also uncovered interpretability issues with screen-based indicators: similar to findings reported earlier by Portnoff et al. [PLE+15] in the context of LED status lights, the mental linkage between display and camera/display and self is not effectual. This is an issue that was hypothesized (c.f., Section 4.3 and [KWB18]), but which is also counter-intuitive and of severe impact, as screen-based indicators are already employed in practice, e.g., by the Deutsche Bahn security personnel [Con16]. Then again, our study did not provide bystanders with prior knowledge (e.g., through media coverage) and thus might differ from existing police or security body cams. Nevertheless, existing screen-based body cams might have to be re-evaluated in terms of how much prior knowledge they require to be understandable, and whether verbal explanations or media coverage might indeed suffice. In addition, the results we presented in this chapter indicate that a any indicator is likely superior to no indicator, and substantiate our design recommendation to employ candid status indicators to increase social acceptability. For future work, we consider status indicators that employ physical occlusion as a promising alternative to screen-based or point light indicators.

7 Discussion and Conclusion

Interest in determining and designing the social acceptability of a human-machine interface or a (novel) interaction can have numerous motivations, including reducing the user's risk of stigmatization, misconceptions and negative judgment through others; Aspects of technology use that are often emotionally charged and that contribute to user experience. Our survey of current practices of addressing social acceptability in HCI (**RQ1**, Section 2.2) showed that social acceptability does not receive equal attention in all phases of the human-centered design process, as illustrated in Figure 7.1.

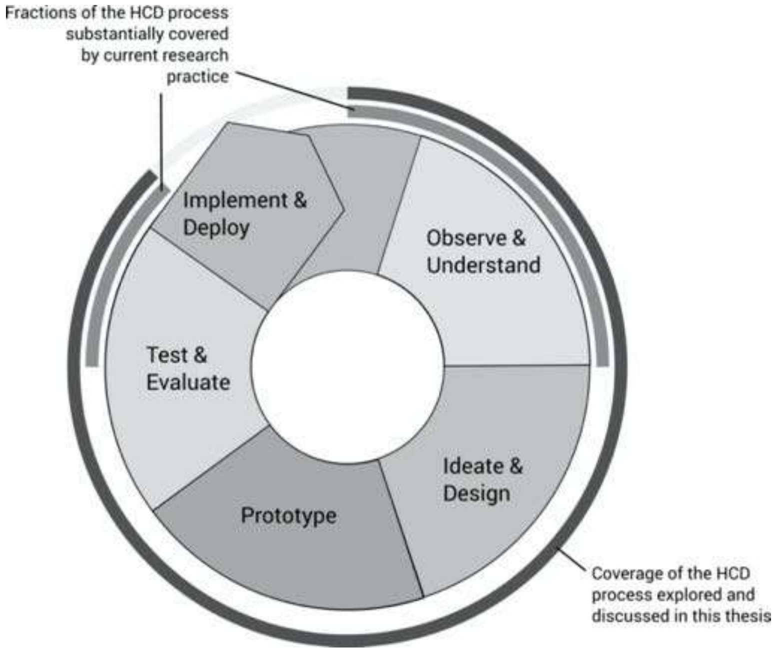


Figure 7.1: The majority of research on social acceptability in HCI covers only a fraction of the human-centered design process. In this work, we explored all phases of the human-centered design process.

Throughout Chapter 3 to 6, we exemplified how to design for social acceptability; Specifically, by addressing and including social acceptability aspects in all phases of a human-centered design process. In this chapter, we extend the focus from the individual phases to the HCD process as a whole. In Section 7.1 we holistically reflect on the four chapters from a design perspective: *Observe & Understand* (Section 3), *Ideate & Design* (Section 4), *Prototype* (Chapter 5), *Test & Evaluate*, and *Implement & Deploy* (Chapter 6). We illustrate how human-centered design (HCD) can serve to design for social acceptability by closely intertwining empirical user research and concrete design decisions. With Section 7.2 we contribute a discussion and reflection from a methods perspective that may serve as reference and "toolbox" for developers, engineers, designers and researchers with an interest in social acceptability. Finally, we address future research challenges (Section 7.3), our most significant results and contributions (Section 7.4). We conclude by reflecting on our work and with an ethical perspective on researching social acceptability in HCI (Section 7.5).

7.1 Design Strategies for Socially Acceptable Body-worn Cameras

The design activities in Chapter 3 to 6 focused on the research question

> **RQ2:** How can we meet both the user's and the bystander's needs, goals, and values while designing socially acceptable body-worn cameras?

We now reflect on the design strategies developed to address RQ2. We detail on how user and bystander needs motivated our design activities. Subsequently, we summarize key findings from user research (marked 1. - 9.) and outline how they shaped the process of prototype creation. Last but not least, we conclude by reflecting on two design strategies that arise from user and bystander needs: unobtrusiveness and candidness. In summary, this reflection exemplifies how **findings from empirical research (e.g., user studies) can motivate concrete design decisions that are proactively oriented toward influencing social acceptability**.

Starting Point: Understanding User and Bystander Needs

In order to answer RQ2, we conducted an in-depth investigation of *user and bystander needs, goals and values*. While many core findings originated from the focus group and lab survey presented in Chapter 3, user studies in the later chapters added to the overall picture and verified needs that we had previously identified from prior work. **Overall, we identified six conflicting user and bystander needs, namely functionality, comfort and justification (user), and privacy, control and notice (bystander)**, as summarized in Table 7.1. Our work shows that **these conflicting needs are the root of social acceptability issues with body-worn cameras**, as arising user – bystander conflicts impact on the user's impression management. From a user's perspective these goals and needs comprise to make use of the camera device as intended, e.g., for photography or visual tracking [KKM15; BBV+19], and in a satisfying and comfortable way, e.g., without cumbersome procedures to acquire bystander consent [HTA+14; KAC+18; KB19]. Simultaneously the bystander has equally warranted needs for protecting their visual privacy [DDK14; KKM15; HVC+15]. From a bystanders perspective there is also the need for situation awareness and desire to be notified about camera presence [KKM15; HVC+15; ASV+18; BBV+19], as well as the need for some level of control over devices that might potentially impact on their own visual privacy [NMH+09; DDK14; SNS+16]. The right to personal privacy is a fundamental value that is not only shared by both users and bystanders, but essentially both-ways, as one individual can take take the role of user and bystander at the same time: one individual might wear a camera device while being bystander to another user of a wearable camera. With this in mind, it is unsurprising that users are often found to be concerned about bystander privacy, in parts more than bystanders themselves [HTA^{+}14; KHB17]. In consequence, camera wearers display a need for justification, i.e., to provide a valid explanation for their camera usage [NMH^{+}09; KHB17; ECK17; ASV^{+}18; AKP^{+}18]; Reflecting values such as responsibility for one's own actions and honesty. The need for justification – specifically what the camera device is being used for – has been verified by multiple researchers [ASV^{+}18; AKP^{+}18; BBV^{+}19; HVC^{+}15] after being hypothesized and confirmed in our own prior work [KKM15]. This finding is one of the core premises of our design activities.

User	**Bystander**
Functionality: *I would like to be able to use my device.*	**Privacy**: *I don't want to show up in someone's video stream.*
Comfort: *I don't want to worry about asking bystanders for consent.*	**Control**: *I would like to have the option to object to being recorded.*
Justification: *I do not want anyone to think I'm doing something illegal.*	**Notice**: *I would like to be aware of cameras that might record me.*

Table 7.1: Social acceptability issues with body-worn camera arise from conflicting user and bystander needs, here illustrated by exemplary user statements (left) and bystander statements (right).

The individual and aggregate results from our user studies contribute to a better understanding of social acceptability issues with body-worn cameras. However, in the context of this work, we do not stop at *Observe & Understand*. Instead, our empirical findings serve as a starting point for targeted design activities that aim to resolve or alleviate the conflict between user and bystander needs and goals, and credit their shared values.

From User Need to Design Strategy

Our vision is that social acceptability issues identified from empirical user research should motivate and drive design activities. In the following we discuss how the identified conflicting user and bystander needs, as well as key findings (marked 1. to 9.) from the individual user studies incrementally shaped our overall design process. By providing this holistic view on our design process we exemplify one approach to *designing socially acceptable body-worn cameras* following human-centered design (HCD).

Starting out from a focus group on smart glasses allowed us to conclude

> 1. Recording matters (Section 3.1).

This is the case, because the integrated camera is perceived a threat to bystander privacy, and the user's impression management. It is intensified by the camera's "always-on" nature, which is a result of the wearable form factor, leads to a lack of notice and justification: bystanders cannot determine whether the device is recording, user's feel a need to justify themselves wearing the device. It is notable that the latter need also applies when the device is worn, but turned off, used for applications that do not require a camera, or for camera applications that do not store imagery persistently, e.g., object recognition or tracking.

Based on "recording matters", we employed *candidness*, i.e., device characteristics or behavior that communicates the camera status (e.g., "ON" or "OFF"), and the camera device's intention of use. Information-wise, we focused our approach to candidness on information related to the camera, or its ability to record – an approach which is very different to prior viewing angles. In his keynote "Wearable Computing: Through the Looking Glass" at Ubicomp 2013 Thad Starner details on the design considerations behind the design of Google Glass: while their design attempted to integrate "Social Cues" into the design of Google Glass[1], they focused on the "barrier between [the user] and the conversational partner" induced through the device's display. In contrast to earlier head-mounted displays which occluded the wearer's pupil, Google Glass introduced a transparent display whose

[1] T. Starner, Wearable Computing: Through the Looking Glass, Ubicomp'13 Keynote, `https://ethz.ch/content/vp/en/conferences/2013/ubicomp/e4778f17-c2d1-4973-85dd\-b0275b218df8.html`, Video at 00:10:46, accessed 2019

screen contents were "viewable by the conversational partner". This characteristic implements candidness, as it provides the bystander with information about the application accessed by the user. This approach is promising and might also be relevant to social acceptability, as maintaining eye-contact is essential to human-human interaction [MP06]. It, however, is not targeted at the camera's recording capability – the major cause of concern and conflict.

Our pursuit of *candid communication of camera status and intent* as a design strategy to increase social acceptability is further backed and motivated by our empirical results:

> 2. Communicating the intention of use significantly improves user attitudes, and can raise a devices social acceptability (Section 3.1).
> 3. A majority of lifelogging camera wearers prefers to wear their devices openly instead of concealed to avoid being accused of surreptitious photography (Section 6.2).
> 4. Research prototypes featuring camera-related candid elements were recognized positively for increasing transparency (Section 6.1), and for providing reassurance (Section 5.2).

Unfortunately, candidness is challenging to implement and to date there is a lack of best practices, or recommendations how to achieve it. Ens et al. suggested various conceptual scaffolds, including Augmented Reality, and an application on the bystander's smart phone to realize candid interactions [EGA+15]. This line of design is, however, not applicable to body-worn camera use in public, as our user studies indicated:

> 5. Bystanders should be able to "come-as-they-are" (Section 4.1).
> 6. It is considered unethical to put the strain of privacy protection, or "opting-out", on bystanders (Section 4.2).

These findings indicates that requiring bystanders to possess gadgets or have access to wireless connections for privacy protection is unfavorable. In consequence, there are limited design options available, as noted by Alharbi et al.: *"[...] when among strangers, communication of privacy-preserving techniques on data factors[2] is not feasible. Therefore, only device recording affordances based on visible characteristics can affect social presence among strangers"* [ASV+18]. The use of device affordances introduces an additional challenge: From a bystander perspective, other persons' wearable devices are some kind of a "walk-up-and-interact"

[2] Alharbi et al. name "type of audience with data access", and "data collected attributes" as data factors, i.e., what data is collected and who has access to it.

or at least “walk-up-and-understand” interface. They must be comprehensible without prior knowledge. Therefore, we undertook a range of design activities to determine design incentives for privacy notices that are sufficiently noticeable, understandable, secure and trustworthy. Our results highlight that:

> 7. Metaphors, specifically physical occlusion, are beneficial in terms of understandability, security and trustworthiness (Section 4.3).
>
> 8. Notice and consent only work in combination: notice needs to be provided **before** a recording, and with an option to consent or object (Section 4.3).
>
> 9. Manual control by the user is perceived as cumbersome, requiring bystanders to manually opt-out as unethical: automatic privacy protection and granular, manual control need to be balanced (Section 4.1, 4.2).

Key finding 7. provides insights about the *how* and *where* of designing privacy notices. The latter two findings (8. and 9.) are highly relevant to the *timing* in systems design: acquisition of consent or protection of bystander privacy, respectively, should happen *before* a picture is taken. Notifying a depicted person afterwards is not sufficient (albeit close to current practices). In consequence, we aimed for designs that realize proactive, i.e., automatic, privacy protection, but leave room for manual intervention (e.g., through the use of gestures).

The prototype which reflects the design considerations outlined above most, is PrivacEye (Section 5.2). PrivacEye implements proactive privacy protection by automatically reacting to the privacy-sensitivity of a situation. It furthermore employs a physical shutter to occlude the camera lens, which communicates the camera status and provides reassurance. Although not implemented in our current prototype, we might envision the integration of manual, more granular privacy controls, e.g., gestures. Furthermore we envision PrivacEye as forerunner of proactive privacy-sensitive smart glasses that might take form factors more closely resembling prescription glasses. We understand the mechanical shutter as essential design feature, albeit it would have to be decreased in size, or replaced by a liquid crystal light valve, a LCD controllable black-out panel, small in size that knows two states, opaque or transparent[3]. Current state-of-the art technologies in miniaturized eye tracking (e.g., Pupil Invisible[4]), and head-worn display technologies (e.g., North’s Focals[5]), could – in combination – realize this vision.

In summary, our design journey took as from understanding user needs, goals and values over identifying specific concerns (1. Recording matters) to strategies to

[3] In early 2020 One Plus showcased a similar occlusion effect on a smart phone’s rear camera [Goo20] – similar to the concept we envisioned 2018.
[4] Pupil Invisible, `https://pupil-labs.com/products/invisible/`, accessed 2019
[5] Focals by North, `https://www.bynorth.com/focals`, accessed 2019

proactively influence socially acceptable design (2. - 4.). Keeping the human in the center, we considered implementation constraints (5. - 6), and design requirements (7. - 9.). Finally, we motivated a proof-of-concept implementation of privacy-sensitive smart glasses featuring a mechanical shutter, PrivacEye (Section 5.2) and presented our vision of candid, proactive smart glasses that will undergo a miniaturization process to blend in with everyday clothing and accessories. Our **key findings (1. - 9.)** can be understood as **design incentives for future work that will guide this process**.

Unobtrusiveness and Candidness: Contradiction or Not?

To date, unobtrusiveness (or subtlety) and candidness have been discussed as opposites in prior work [EGA+15], including our own [KHB17; KEC+17]. Yet, our in-depth literature analysis (Section 2.2) indicates that both, unobtrusiveness and candidness are beneficial for social acceptability. Our analysis also showed that in the context of social acceptability unobtrusiveness is rather understood as "not calling attention" than "hidden" or "deceptive" (see also [PMH19]). In consequence, we believe that it is possible to create candid behavior and indicators (e.g., lens occlusion) that are noticeable enough to bystanders, but blend in with other (information-carrying) attributes (e.g., clothes) to not call attention to the wearer.

7.2 Designing for Social Acceptability?!

Challenged by the question "is it possible to design for social acceptability?", one of the objectives of this thesis is to evaluate how social acceptability can be integrated as design goal in the HCD process. In Chapter 2, we criticized that 1) social acceptability is not considered throughout the whole HCD process, and that 2) participatory design, and user studies in unconstrained settings are underrepresented in the body of existing work. In this section we re-consider those points of criticism in light of our own design activities, and address the research questions

> **RQ3:** Which methods are suitable to inform the design of socially acceptable human-machine interfaces?

We present and discuss the spectrum of methods that has been applied in a HCD process (see Figure 7.2). Subsequently, we discuss the explored methods and how they can inform the design of socially acceptable human-machine interfaces. We further elaborate on where tools, e.g., card decks, can assist in this process. In summary, our discussion may serve as **a "toolbox" from which to choose suitable research methods for designing social acceptability.**

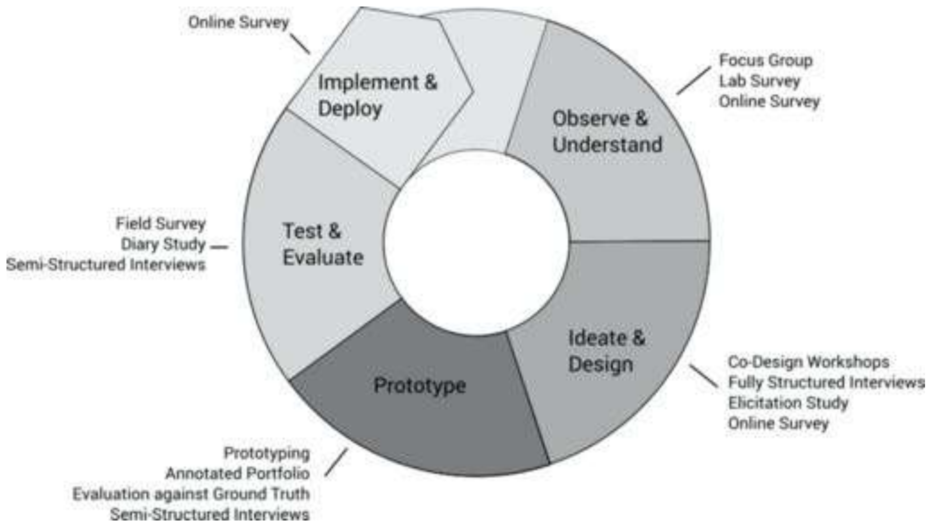


Figure 7.2: Throughout this work we employed a range of different methods. Here, we map them to the human-centered design process.

Tools for Determining (Design) Factors Affecting Social Acceptability

What is perceived as socially acceptable largely depends on the user's *needs, goals and values*, as these direct how they would like to present themselves in social context. In this thesis, we employed a number of methods to better understand how design can accommodate these needs, and how design factors and contextual factors increase or decrease social acceptability. From **focus groups** (Section 3.1), and **semi-structured interviews** (Section 5.2), we were able to identify concerns and expectations. We additionally used an **online survey** (Section 6.2) to inquiry current existing practices of a sparse, regionally distributed user group: lifelogging camera users. This combination proved highly beneficial, as it allowed to contextualize expectations (prior to device usage), and **expert assessments** (Section 3.2) with experience from actual device usage. We would recommend **combining these four perspectives, envisioned and actual usage, expert and user accounts**, in future work, as all of them have both strengths, and limitations (e.g., bias).

Moreover, we made use of **scenarios**, an established technique for evaluating social acceptability (see literature review in Section 2.2), and utilized different types as stimuli in a **lab survey** (Sections 3.1 and 3.2), and a **online survey** (Section 4.2). In both studies, we decided against photo-realistic footage (e.g., used in [SRR+18] or [LSC+09]), as illustrations (3.1) and virtual animations (4.2), both do not require actors, and thus are less likely to introduce racial, cultural or gender bias. In addition, they are better replicable and easier to extend.It has to be noted that all types of scenario-based evaluations are limited due to the presence of an imaginative component, as discussed by the participants during our workshop on social acceptability at CHI 2018 [KOW+18; KOM+19].

Furthermore, user studies relying on a selection of image or video prototypes, do not provide absolute measures, i.e., cannot answer whether an interface would reach a certain acceptability threshold in practice. They provide only relative measures. However, this allows to isolate certain features and compare variants against each other, which provides accurate *relative validity*. The advantage of being able to isolate design-relevant features is also illustrated by our study: through our usage of pictographs we were able to isolate the variable "knowledge about usage intentions" and provide quantitative proof that known usage intentions significantly improve social acceptability. Therefore, **we value the scenario-based approach as a relatively low-cost method that allows generate concise design incentives** (c.f., Section 3.1). Such singled-out aspects can then be targeted through design.

Tools for Making Design Choices Accessible during Participatory Design

A second group of methods we explored, originated from **participatory design**. In participatory design, users become active co-creators (instead of re-active informers), and the researcher becomes partner and facilitator (instead of investigator). We successfully employed an **elicitation study** (Section 4.2 to actively involve users in the creation of a gesture vocabulary for opting-in and opting-out of a camera's recording. In the context of involving novel, and potentially controversial technologies, designing more complex procedures (e.g., for privacy mediation) with non-expert audiences, e.g., citizens, in joint co-design activities can be hindered due to (technological) knowledge gaps. As a remedy, we compiled technical background knowledge, in our case state-of-the-art procedures and concepts for privacy mediation, and provided participants in **co-design workshops** with this information in form of a **card deck**. The application of card decks in participatory design is established, highly beneficial, and well researched [MGV$^+$14; WRB17], however, not in this specific context, knowledge provision. Our experiences (Section 4.1), showed that **dedicated card decks can facilitate a constructive atmosphere, support participants in creating solutions, and prevent non-factual, binary, and emotionally loaded discussions**. The **Privacy Mediation Cards** are only suitable for a limited application area and do not cover or apply to other types of technology. The underlying concept, i.e., **provision of a mutual basis of (technical) knowledge in card form** is transferable to other application areas and applicable in the context of controversial on not socially acceptable technologies or design. We believe that knowledge-based, and solution-oriented participatory design is essential to create designs that meet social expectations, as users (and not researchers) are the experts on their own, everyday social life. Our card deck proved to be a useful tool in this process. We would envision similar card decks, modeled after our Privacy Mediation Cards, to be equally utile.

Tools for Facilitating the Innovation of Form Factors

We addressed the need to innovate form factors of body-worn cameras through two approaches: **co-design workshops** with expert participants (Sections 4.3) and **prototyping** (Sections 5.1, and 5.2). Main difficulties of the co-design methods included overcoming the focus on established, but not optimal design solutions (status-quo bias, c.f., [SZ88]), and the abstractness of the involved concepts, e.g., visual privacy. We employed **structured brainstorming activities**, to promote out-of-the-box thinking using the **Lotus Blossom Technique**. The Lotus Blossom Technique [Mic14; Tat90] is a problem-solving approach which – with each layer of petals – successively reveals more and more detailed solutions to a design problem. The method balances structure and flexibility and fosters imagination and innovative thinking, while it is also easy to use and explain [Hig94; Hig96; Smi98]. In addition, we employed **quick-and-dirty prototyping** to further ideate and communicate concepts. We provided a material box equipped with various materials and making tools inspired by IDEO's Tech Box (c.f., Greenberg et al. [GCM+13], p.58) that served to create **low-fidelity artifacts**. We found this approach to be highly beneficial, as **the usage of low-fidelity artifacts fostered creative ideation, successfully supported critical debates, and proved highly potent in exposing conceptual flaws**, e.g, through exaggeration (c.f., the "Kinder Surprise" issue of timing).

In addition, we created research prototypes to explore socially acceptable design features, including physical occlusion of the lens, integrated display, and proactive, context-sensitive behavior. While **low-fidelity prototyping techniques** have proven useful to visualize and communicate design ideas, we found the implementation of functionally more mature prototypes to be challenging in terms of miniaturization, and fidelity. To explore different aspects of design and implementation, we utilized a range of **physical and virtual prototyping** techniques (presented as **annotated portfolio**, Section 5.1). Each of the explored approaches has their strengths and limitations. For instance, **Augmented Reality** prototypes allow to accurately re-create aesthetics and visual appearance of products, and provide the designer with high flexibility in terms of functions that can be simulated or implemented. On the other hand they also confine the available evaluation options (e.g., requiring specific hardware, or pre-recorded videos), and lack physicality. In contrast, **fully functional physical prototypes** have the advantage that they can be taken into the field, but come at the cost of increased size and decreased fidelity, i.e., there are limits to the achievable resemblance to consumer products. In summary, all of the presented and critiqued prototyping approaches have both, strengths and limitations, and require compromises. By presenting our experiences with a variety of **mixed fidelity prototyping techniques** we illustrate that **limitations of individual prototyping techniques can be mitigated by combining multiple, complementary approaches**.

Evaluating Social Acceptability in Lab and Field

We furthermore employed methods to test and evaluate the effect of design features on social acceptability. These included **semi-structured interviews** along with **Wizard-of-Oz style prototype demonstrations** (Section 5.2), as well as **field surveys** with fully functional wearable camera prototypes (Section 6.1). Participants in the latter study acted as co-investigators (or proxies) and, following a **paratyping** principle, collected feedback from bystanders on the camera device they were wearing. While this study type also allows for other options to document bystander feedback (e.g., distributing answer cards, c.f., Iachello et al. [ITA^{+}06]), we asked our participants to note down the feedback they collected along with their own subjective impression in a pen-and-paper notebook (**diary study**). This procedure has the advantage of a low entry barrier to collecting feedback, and the potential to also capture non-verbal reactions. On the downside, it may also involve the risk of bystander feeling hesitant to express their feedback to the wearer. Our field survey further showed the importance of fully taking into account the usage experience, even when aiming to "only" elicit bystander feedback: social acceptability is closely tied to utility, and thus bystander judgments may depend on the device's purpose and usefulness. In our case: whether the wearer gets to keep the images. The wearer's role as proxy causes their ongoing task to be disrupted for collecting feedback. However, explicitly collecting reactions by asking bystanders about their experience without disrupting the user (c.f., Lucero et al. [LV14]), is only possible with the experimenter present, e.g., in staged **lab or field experiments**. While we opted for an uncontrolled setting due to the broader range of covered situations and higher ecological validity, staged experiments allow for more control, and increase replicability and comparability, i.e., internal validity. If the context of use is well-defined, experiments with simulated context in controlled settings, potentially with scripted interactions provide a viable and appealing alternative (c.f., Jarusriboonchai et al. [JOV14]).

Reflection

There is not "the" method for designing social acceptability. All of the methods we used for the research presented in this thesis have their strengths and limitations. However, their combination proved highly potent in overcoming the individual method's limitations and in bridging the gap between empirical observation and socially acceptable design solution. For instance, rating individual design elements (e.g., interaction techniques) in terms of their social acceptability is a powerful tool, but can come at the cost of introducing a lack of context – which can be compensated through complementary qualitative inquiry or ethnographic observation. Similarly, a combination of methods allows to anticipate that informers (e.g., experts) or the designer(s) themselves might be wrong: for example, the "integrated display" design strategy was rated well understandable by experts in our co-design workshops, but found to be not sufficiently understood by bystanders in our field survey.

The set of methods we presented is certainly not the only one suitable to inform the design of socially acceptable human-machine interfaces – and not intended to be. In contrast, we understand the methods we used to design socially acceptable body-worn cameras in this exemplary HDC process as starting point; The methods we used and discussed here may serve as a "toolbox" for other researchers to choose from, expand on, and to evolve further. We hope that our exploration of HCD for social acceptability will engender future research to test the applicability of our approach in the context of other technologies, interaction paradigms, and device types.

7.3 Future Directions for Social Acceptability in HCI

In this work we exemplified how social acceptability can be integrated as essential design goal throughout all phases of a human-centered design process: we showed that we can design for social acceptability. However, our contributions alone cannot remediate all social acceptability issues, and how to understand, mitigate, and evaluate them, are still under-researched in HCI. In the following, we outline challenges related to social acceptability in HCI, and motivate directions for future work addressing those challenges.

Methodical Challenges

Evaluating interfaces in terms of social acceptability (or evaluating interfaces that lack social acceptability in terms of something else) is challenging. Issues with social acceptability might hinder usability testing, as user's might be hesitant to interact. Simultaneously, as surfaced through our work, **perceived utility** (Section 3.2 and 6.1) and **knowledge about usage intentions** (Section 3.1) have an effect on social acceptability. Moreover, there is a – yet to explore – overlap between social acceptability and , e.g., aesthetics and attractiveness [QT10], perceived "coolness" [STW14; BRK^{+}16; RBK^{+}17], as well as identification as hedonic quality [Has04]. Thus, **social acceptability would ideally not be evaluated detached from the overall user experience, but as part thereof**. Consequently, future work will require measures to adequately capture social acceptability, but at the same time allow to differentiate between social acceptability, and other constructs contributing to the overall user experience. As highlighted through our literature review, **HCI currently lacks established, standardized questionnaires** (Section 2.2) that parse design-relevant aspects of social acceptability apart, and measure social acceptability in a non-proxied fashion. Starting out from existing questionnaires, e.g., [KG16], future work would have to fill this gap to ensure discriminatory power of measures and comparability, and replicability of results.

> **Future RQ:** How can social acceptability be put in relation to existing user experience constructs?
> **Future RQ:** How can we quantify social acceptability using standardized measures, e.g., questionnaires?

In Section 5.1 (annotated portfolio) we provided an in-depth discussion of different prototyping techniques. While resemblance to consumer or off-the-shelf devices might be inherent or easy to achieve for some research prototypes (e.g., smart phone applications) it can be hard to implement for other areas (e.g., novel types of wearables) where it may potentially skew study results and influence user feedback. Most interestingly, results from our field survey (Section 6.1) suggest that **prototype fidelity might affect social acceptability measures** differently than e.g., usability measures. However, a large-scale quantitative evaluation is still pending. Building on the comprehensive prior work on the relationship between aesthetics and usability (e.g., the controversially discussed notion *"what is beautiful is usable"*) [HM10; TRH+12; TKI00], future work will need to answer how (prototype) appearance influences social acceptability. Then, knowledge about the effect of low, mixed, and high fidelity prototyping on social acceptability measures, will allow to more precisely interpret and contextualize employed measures.

> **Future RQ:** To what extent are social acceptability measures influenced by prototype fidelity?

Similarly, knowledge about the effect of different study settings, e.g., the degree of context simulation, have not yet been studied in-depth. With only one work on social acceptability (Alallah et al., [ANS+18b]) comparing crowdsourcing (online) to laboratory settings, there is a lack of methodical knowledge about research practices involved with the evaluation of social acceptability in HCI. Most notably, popular study methods have not (yet) been evaluated against alternatives, or with respect to potential confounding variables. For instance, field experiments on social acceptability are often staged in highly frequented public locations, e.g., cafés, with the experimenter present. Yet, the effect of choice of location, layout and experimenter presence (c.f., Williamson et al. [WW17]) on social acceptability measures is so far not fully explored. In future work, we will need to compare and verify research methods to learn how different study settings and parameters, e.g., experimenter presence or simulation of social context, might influence social acceptability measures.

> **Future RQ:** To what extent are social acceptability measures influenced through the choice of study setting and parameters?

Technological Challenges and Design Challenges

The work presented in this thesis demonstrates: social acceptability is not only determined through a device's appearance (or how it is worn), but also through its visible behavior. Non-functional, but consumer-like looking mock-ups, can be valuable tools to elicit early initial user feedback, but also misguide expectations (c.f., Holmquist et al. [Hol05]). Simultaneously, specific device behavior desired by the designer might be challenging to implement, or even exceed the capabilities of state-of-the-art tools. These combined technological and design challenges can only be addressed jointly. For instance, our PrivacEye prototype (Section 5.2) was motivated by the design need for an option to automatically open and close a physical shutter in front of a camera lens. Solving the technological challenge, eye movement-based activity recognition, then allowed to better address the user's and bystander's needs for comfort, privacy protection and reassurance.

We expect similar needs to require not only novel form factors, but also innovations in artificial intelligence, display technologies, or material science. For example, impression management (Section 2.1) warrants a need for information control: too much information can stigmatize the user or pose a threat to their privacy; Too few information might fail to justify device usage in certain contexts. Albeit explored to some extent in prior work [EGA+15; JMO+16], current devices and display materials are not fully capable of enabling this kind of asymmetrical information access, where user's and bystander's are provided with the same information, but with different level of detail. Thus, a possible future research question might again combine both, technological (*how to display*) and design challenges (*what to display*).

> **Future RQ:** How can we create displays that balance user privacy and bystander awareness by providing asymmetrical information access?

Ethical, Political and Social Challenges

Aspects that make a technology non inclusive can trigger ethical concerns. These aspects might include poor availability, low accessibility, or a (perceived or real) lack of fairness (e.g., in algorithmic systems). Design that neglects some standpoints, perspectives, circumstances or contexts, i.e., technology that works only for few, or causes disadvantages for certain people is likely to be considered not socially acceptable. As noted previously by Henze and Kunze, technologies that *"enable superhuman abilities [which] will raise social inequalities to new levels"* [HK17]. Simultaneously, **a lack of social acceptability in a human-machine interface (e.g., due to unusual looks, or risk of stigmata) can reinforce existing inequalities**. As noted by multiple researchers, the practical every-day usage of assistive devices is often restricted due to social stigma and misconceptions [SW11; PSM+16]. However, Ahmed et al., provide evidence that bystanders would be willing to share more information with visually impaired users than with sighted users. They found their participants to be *"more inclined to give 'equality' than 'equity'"* [AKP+18]. Hence, we are confident that there is room for a carefully designed, socially acceptable middle ground in interface design to be explored in future work.

We further note that social norms, which influence social interactions with and without technology, are under constant re-negotiation. We are convinced that, albeit social norms may change over time, **it is essential to fit interface design to existing norms, and not expect users and non-users to get used to it** (as frequently suggested). From our perspective, it is also not expedient to just "better educate people", e.g., about whether risks for bystanders are perceived or actual. Instead, we believe that design must not presume users or non-users having the resources (e.g., time, tech-savvy, cognitive abilities) for risk assessment, but instead provide suitable information or reassurance (e.g., through status indicators). Most importantly, it is the designers' responsibility to create interfaces that **meet the requirements needs, goals, and values of both, users and non-users**. Adjusting the interfaces we create to the societal reality (and not vice-versa) requires us, interaction designers, to be open, critical and constructive, and to embrace interdisciplinarity.The insights provided in this thesis will help to guide these efforts.

7.4 Summary of Research Contributions

- We contribute an analysis of current research practices based on 69 HCI papers on social acceptability. Most significantly, we identified an unbalanced distribution of study approaches and a lack of interlacing between empirical and artifact-creating approaches. This "missing link" causes a discrepancy between design recommendations based on user research, and design strategies employed in artifact creation.
- We identified contexts in which smart glasses usage is perceived as controversial, and found perspective, recording capability, and knowledge about usage intentions to influence user attitudes towards smart glasses with statistical significance. We contextualize these results by eliciting expert opinions on how to rank factors influencing smart glasses adoption.
- We contribute insights about usage behavior of lifelogging camera wearers, whom we found to wear their camera in an open, unconcealed way.
- We provide indications that screen-based status indicators are received positively for increasing transparency, but frequently misinterpreted and not well understood by bystanders.
- We contribute an annotated portfolio of prototyping techniques for smart wearable cameras utilizing candid behavior and form factors.
- We contribute a proof-of-concept prototype of eye tracking enabled smart glasses featuring de- and re-activation of an integrated camera by physically occluding the lens with a mechanical shutter, which is perceived to act reassuringly and increase user and bystander comfort.
- We investigated suitability and choice of gestural Opt-in and Opt-out controls, which should (1) employ gestures that are not a priori beset with meaning, but associated with "recording" or "picture taking', (2) offer complementary gestures for both, Opt-in, and Opt-out, and (3) employ extendable gestures to enable granular, non-binary privacy control.
- We derive 3 design recommendations for status indicators of body-worn cameras: (1) meaningful combination of notice and consent, (2) avoidance of elements that have to be known or learned, and (3) provision of proactive, contextual and reassuring mechanisms.
- We contribute a card deck on privacy mediating technologies and procedures for body-worn cameras that succeeds in facilitating participatory design sessions, and is available as print-on-demand [Koe19].
- Reflecting on the methods used throughout this thesis, we contribute insights about evaluating social acceptability in various types of user studies, involved challenges and pitfalls, as well as areas for future research.

7.5 Closing Remarks

Both taking pictures, and the option to object to having one's picture taken, can be understood as essential, modern-day rights. These rights collide, when *body-worn cameras* are used (or worn) in public. There, they face significant social acceptability issues. Motivated by the tension between highly promising application scenarios, and legitimate privacy concerns, we focused our design activities on *designing body-worn cameras in a socially acceptable way*. Based on insights from an in-depth investigation of concerns, user attitudes and expectations (Chaper 3), we designed mechanisms that mediate between bystander and user, and provide both with control and situation awareness (Chapter 4). We translated these designs into a range of research prototypes implementing *candid and reassuring mechanisms*, and *proactive, privacy-sensitive device behavior* (Chapter 5). Finally, we contribute insights from using candid and off-the-shelf body-worn cameras in everyday social contexts (Chapter 6). Our exemplary human-centered design process opens a novel approach and a productive context, *where social acceptance is not only an observed phenomenon, but drives the design process.*

As technology changes and advances to enable novel human-machine interactions, the potential for misuse increases. Interaction design knows the term "dark patterns" for *"instances where designers use their knowledge of human behavior (e.g., psychology) and the desires of end users to implement deceptive functionality that is not in the user's best interest"* [GKB+18]. Just as with UI design [GKB+18], proxemics [GBV+14], and home robotics [LC19], knowledge about design features that influence social acceptability may be used to the user's disadvantage. For instance, candid and reassuring features, e.g., the physical lens cover we suggested, could be employed to focus the user's attention and distract from other threats, e.g., other means of data collection ("Misdirection", [GKB+18]). Providers of systems incorporating artificial intelligence (e.g., to realize proactivity) might exploit the user's desire for comfort and justification, and the opaqueness of machine learning: they might proclaim to require more personal information (e.g., about social connections, or offline behavior) to train and enable the service than needed ("Forced Action", [GKB+18; CEV+19]). Similarly, including diversionary, non-medical features in health devices (as suggested by Bright and Coventry [BC13]) increases social acceptability by drawing away the attention from the device's medical purpose. Yet, the additional, non-medical feature (e.g., digital payment for shopping [ACC+13]) may also serve to coerce the user to share more of their information (e.g., with the health insurance provider) than they intended ("Privacy Zuckering", Gray et al. [GKB+18]).

In summary, knowledge about how to design for social acceptability can be used for both, the user's benefit and detriment. Future research will have to face and anticipate this challenge. With the work contained in this thesis we contribute to a more grounded understanding of social acceptability in HCI that will allow to design responsible technology that meets ethical standards, and the needs, goals and values of societal and inter-personal interaction.

Appendices

A Contributing Publications

The research conducted in the context of this dissertation has been comprehensively published in highly selective, peer-reviewed outlets, and presented at renowned international venues. Below, I individually list the contributing publications.

Full and Short Papers

[**KKM15**] M. Koelle, M. Kranz, and A. Möller. Don't look at me that way!: Understanding User Attitudes Towards Data Glasses Usage. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 362–372, New York, NY, USA. ACM, 2015

[**KEC$^+$17**] M. Koelle, A. El Ali, V. Cobus, W. Heuten, and S. Boll. All about Acceptability?: Identifying Factors for the Adoption of Data Glasses. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 295–300, New York, NY, USA. ACM, 2017

[**KWB18**] M. Koelle, K. Wolf, and S. Boll. Beyond LED Status Lights - Design Requirements of Privacy Notices for Body-worn Cameras. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction*, pages 177–187, New York, NY, USA. ACM, 2018
TEI 2018 Best Paper Award.

[**KAC$^+$18**] M. Koelle, S. Ananthanarayan, S. Czupalla, W. Heuten, and S. Boll. Your Smart Glasses' Camera Bothers Me!: Exploring Opt-in and Opt-out Gestures for Privacy Mediation. In *Proceedings of the Nordic Conference on Human-Computer Interaction*, pages 473–481, New York, NY, USA. ACM, 2018

[**SKH$^+$19**] J. Steil, M. Koelle, W. Heuten, S. Boll, and A. Bulling. PrivacEye: Privacy-preserving Head-mounted Eye Tracking Using Egocentric Scene Image and Eye Movement Features. In *Proceedings of the ACM Symposium on Eye Tracking Research & Applications*, 26:1–26:10, New York, NY, USA. ACM, 2019
ETRA 2019 Best Demo/Video Award.

[**KAB20**] M. Koelle, S. Ananthanarayan, and S. Boll. Social Acceptability in HCI: A Survey of Methods, Measures, and Design Strategies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1–19, Honolulu, HI, USA. ACM, 2020
CHI 2020 Honorable Mention Award.

Extended Abstracts

[**KHB17**] M. Koelle, W. Heuten, and S. Boll. Are you hiding it?: Usage Habits of Lifelogging Camera Wearers. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services*, 80:1–80:8, New York, NY, USA. ACM, 2017

[**KB19**] M. Koelle and S. Boll. The Privacy Mediation Cards – A Participatory Design Approach towards Respectful Smart Glasses. In *Proceedings of the CHI 2019 Workshop on Challenges Using Head-Mounted Displays in Shared and Social Spaces*, Glasgow, Scotland, UK, 2019

[**KWH^{+}19**] M. Koelle, T. Wallbaum, W. Heuten, and S. Boll. Evaluating a Wearable Camera's Social Acceptability In-the-Wild. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, LBW1222:1–LBW1222:6, New York, NY, USA. ACM, 2019

Essays

[**KRB19**] M. Koelle, E. Rose, and S. Boll. Ubiquitous Intelligent Cameras – Between Legal Nightmare and Social Empowerment. *IEEE MULTIMEDIA*, 26(2):76–86, April 2019

[**KOM^{+}19**] M. Koelle, T. Olsson, R. Mitchell, J. Williamson, and S. Boll. What is (Un)Acceptable?: Thoughts on Social Acceptability in HCI Research. *Interactions*, 26(3):36–40, April 2019. URL: `http://doi.acm.org/10.1145/3319073`

Organized Workshops

In line with my research efforts, I co-organized a workshop series on social acceptability in human-computer interaction. Workshop proposals are not included in this dissertation, but listed below for completeness.

[**KOW^{+}18**] M. Koelle, T. Olsson, J. Williamson, H. Profita, S. Kane, R. Mitchell, and S. Boll. (Un)Acceptable!?!: Re-thinking the Social Acceptability of Emerging Technologies. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, W03:1–W03:8, New York, NY, USA. ACM, 2018

[**KGS^{+}19**] M. Koelle, C. George, V. Schwind, D. Perry, Y. Sakamoto, K. Hasan, R. Mitchell, and T. Olsson. #SociallyAcceptableHCI: Social Acceptability of Emerging Technologies and Novel Interaction Paradigms. In *Proceedings of the IFIP Conference on Human-Computer Interaction*. Springer, 2019

Further co-authored publications on the subject: [KBC^{+}17], [ECK17], [BKC19], and [MKB19].

B Lab Survey: Scenarios

Overview of scenarios that were obtained from the alternation scheme described in Figure 3.3. For brevity, we are depicting the second-person view with visible usage intentions for the smart glasses condition. Other conditions are analogue. The illustrations follow the conventions **black**: interviewee, **grayed out**: third persons and surroundings, **orange**: the device itself (here: smart glasses). "Thinking bubbles" indicate the visibility of actions performed with the device. Descriptions are provided. The subclause in brackets was only displayed under the visible actions condition.

B.1 Conversational Scenarios

C1) You are meeting in a café. Your date is using smart glasses (to receive a reminder for something important).

C2) You are meeting a business partner. S/he is using smart glasses (to access additional information where necessary).

C3) You are attending a business meeting. The attendee just across from you is using smart glasses (to access additional information).

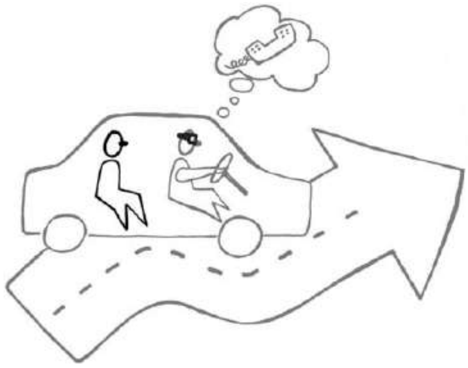
C4) You are celebrating with the extended family. One of your family members is using smart glasses (to take pictures and videos).

B.2 (Semi-)Public Scenarios

P1) You are walking the pedestrian area. A passer-by is using smart glasses (to view navigational hints).

P2) You are walking the pedestrian area. A passer-by is using smart glasses (to make a phone call).

P3) You are sharing a car. The driver is using smart glasses (to view navigational hints).

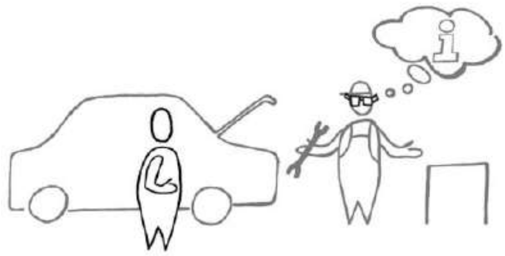


P4) You are sharing a car. The driver is using smart glasses (to make a phone call).

P5) You are taking the subway. The passenger just across from you is using smart glasses (to read a news feed).

B.3 Work Scenarios

W1) You fell ill. The doctor is using smart glasses (to access information on your course of disease).



W2) You are picking up your car at the repair shop. The mechanic is using smart glasses (to access information on the vehicle's specific model).

W3) You are attending an in-house training. The presenter is using smart glasses (to access supplementary information).

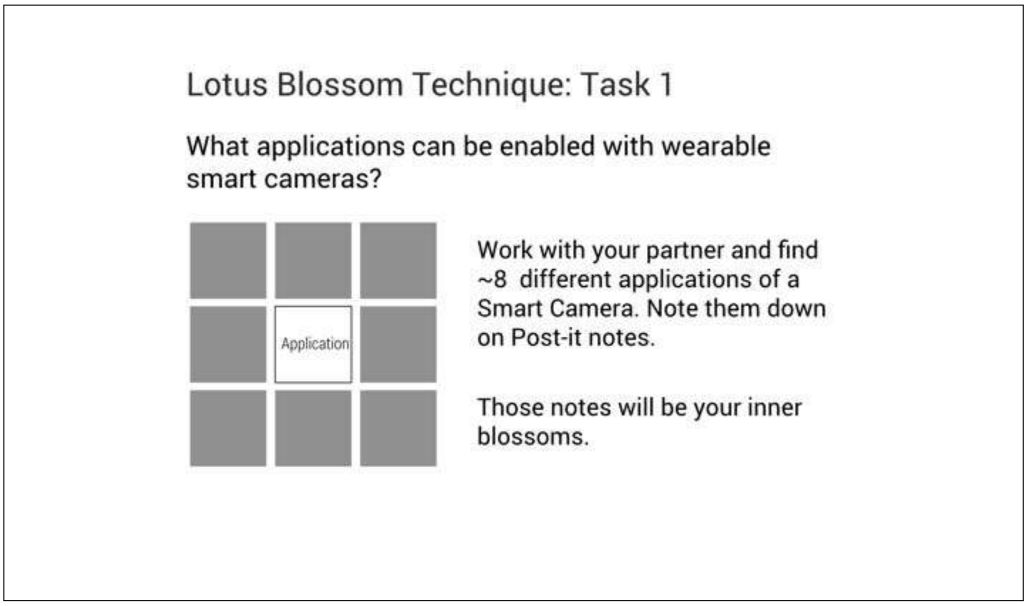
W4) You are customer at a store for electronic equipment. The sales assistant is using smart glasses (to access product information and available stock).

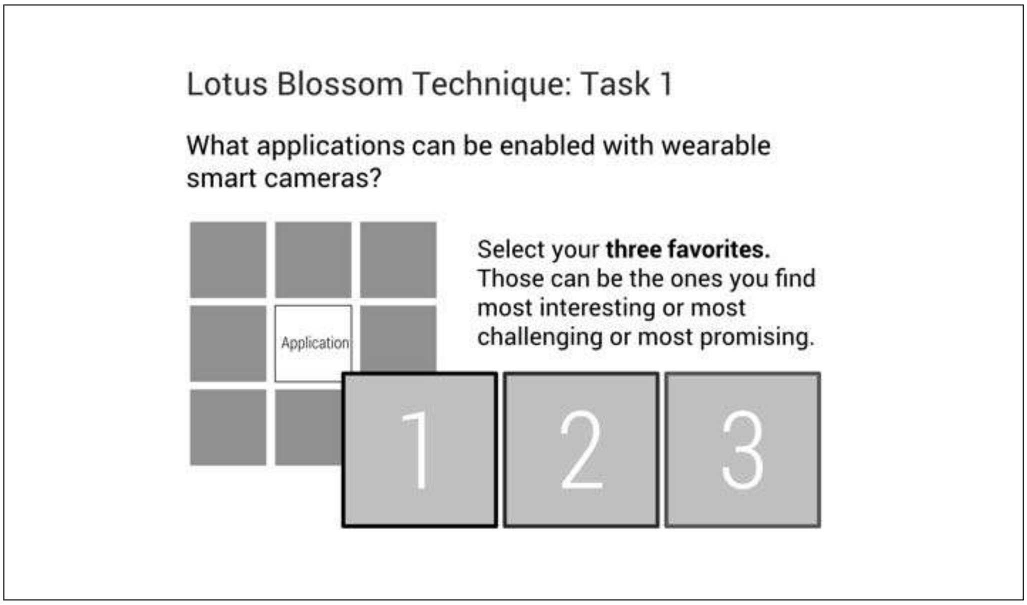
W5) You are customer at a clothes store. The sales assistant is using smart glasses (to access product information and available stock).

C Co-Design: Lotus Blossom Technique

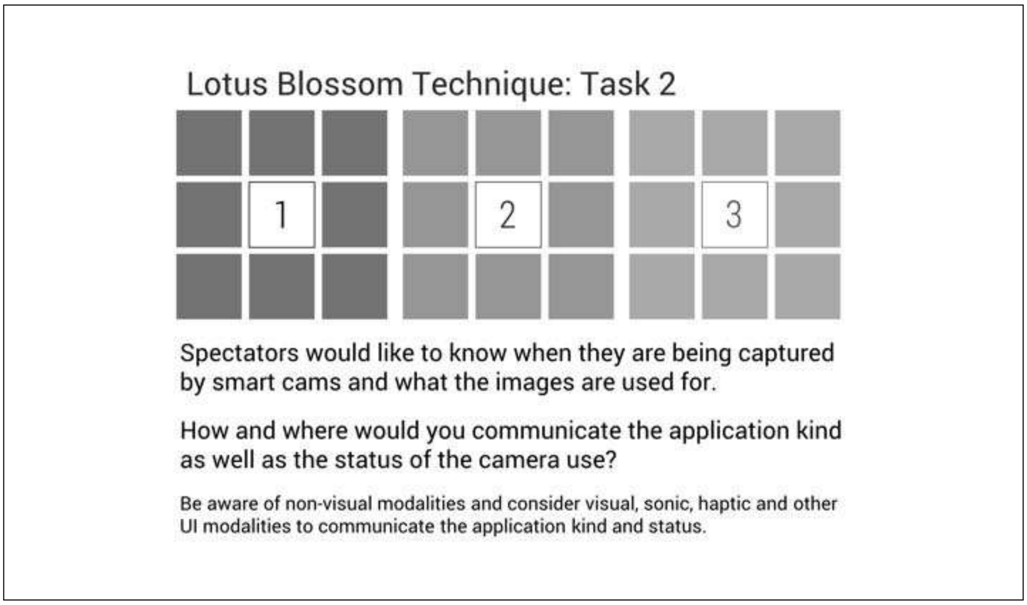
The Lotus Blossom Technique is a popular method for group brainstorming [Tat90; Hig94]. It is a problem-solving approach where each successive step provides a more in-depth look at potential solutions to the problem. Thus, its results largely depend on the questions asked in each step. In our co-design sessions (Section 4.3), we provided the following instructions to the participants.

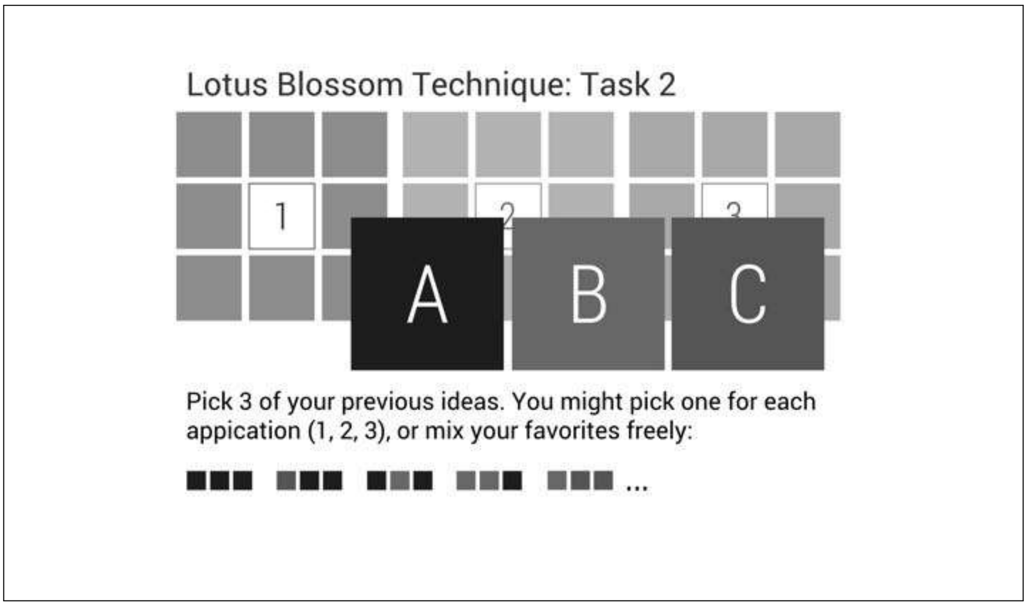
C.1 Task 1



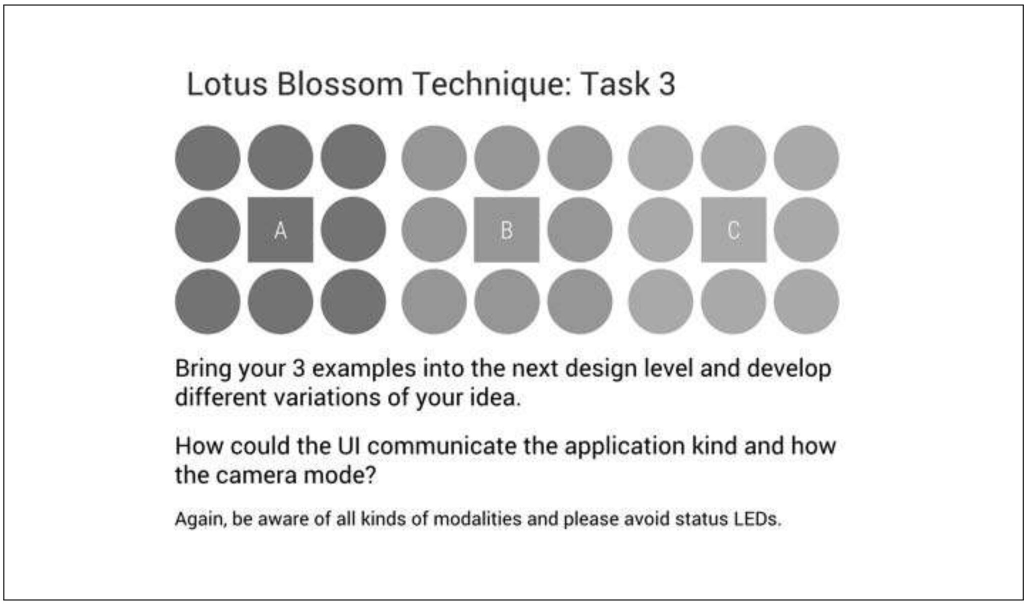


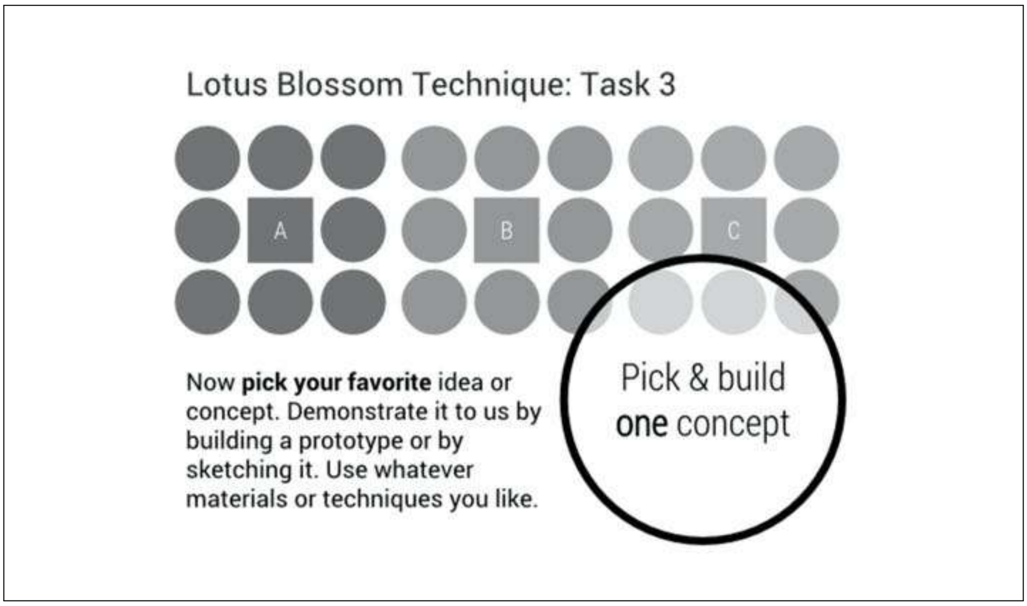
C.2 Task 2


Lotus Blossom Technique: Task 2
1
2
3
Spectators would like to know when they are being captured by smart cams and what the images are used for.
How and where would you communicate the application kind as well as the status of the camera use?
Be aware of non-visual modalities and consider visual, sonic, haptic and other UI modalities to communicate the application kind and status.


Lotus Blossom Technique: Task 2
1
A
B
C
Pick 3 of your previous ideas. You might pick one for each appication (1, 2, 3), or mix your favorites freely:
...

C.3 Task 3


Lotus Blossom Technique: Task 3
A
B
C
Bring your 3 examples into the next design level and develop different variations of your idea.
How could the UI communicate the application kind and how the camera mode?
Again, be aware of all kinds of modalities and please avoid status LEDs.


Lotus Blossom Technique: Task 3
A
B
C
Now pick your favorite idea or concept. Demonstrate it to us by building a prototype or by sketching it. Use whatever materials or techniques you like.
Pick & build one concept

D PrivacEye: Data Set and Video

D.1 Data Set

https://mpi-inf.mpg.de/MPIIPrivacEye/

D.2 Video

https://www.youtube.com/playlist?list=PLyTZd0BHtL6fHAWLssj2QdOIk3H0hErgX

E Field Survey: Study Materials

The participants in the diary study were handed a list of Do's and Dont's, based on [HTA+14] that they discussed with the experimenter in a one-on-one briefing session, as well as a set of information cards.

E.1 DO's and DO NOT's for Study Participants

During this study, you will be carrying a device on your neck (the "MirrorCam Prototype") that will be capturing the environment using a camera, and display the camera's image on an integrated display.
The MirrorCam Prototype does not store any images persistently. The MirrorCam Prototype does not record audio.
The presence of the device might act as an ice breaker or spark interesting conversations. However, it might also trigger privacy concerns. To make the experience of wearing it pleasant for everyone involved, please observe a few guidelines while participating in the study:

DO's

- **DO** keep the harness around your neck with the camera's screen and lens facing out.
- **DO** keep the harness outside of your regular clothing, so that it has an unblocked view of your surroundings.
- **DO** wear the harness so that the camera's screen is observable by those around.
- **DO** explain to persons who may be in the camera's field of view the purpose of the study and the device. Collect their reactions in your diary, where appropriate.
- **DO** offer the informational cards provided, if you encounter anyone who requests more information about the study.
- **DO** pause the MirrorCam Prototype whenever you feel the presence of a camera is inappropriate. Always turn the device off AND put the device away. Pausing the devices saves battery, and allows us to track the frequency of time-outs.
- **DO** put the MirrorCam Prototype away if people around you express discomfort with the device or express their desire not to be in the presence of the camera device.
- **DO** contact us if you have any questions or concerns. We can be reached by email at `studies@offis.de` or `marion.koelle@uol.de`.

- **DO** protect the device from water. For example, please put the device away if you're outdoors and it is raining, or when recreation where the device can get wet.
- **DO** exercise caution with the lanyard so that it does not strangle or choke you. For example, please do not wear it while you engage in sports or while cycling.

DO NOT's

- **DO NOT** write down any identifying information in your diary, including names, phone numbers or email addresses, student numbers, and any information that could be used to identify a person.
- **DO NOT** use the MirrorCam Prototype in places where recording or actions that might be perceived as recording could be interpreted as offensive or a violation of privacy, including: restrooms, locker rooms, changing rooms, bedrooms, and other private spaces where individuals have heightened expectations of privacy.
- **DO NOT** use the MirrorCam Prototype in places where it is, or may be, prohibited or illegal to take pictures, including medical and treatment facilities, museums, secured or restricted areas such as airport security zones, or anywhere else where signage is posted instructing you to refrain from using recording devices.
- **DO NOT** use the MirrorCam Prototype in a classroom setting unless you have the prior approval of your instructor. Explain the purpose of the study and the device to them to obtain informed consent. Collect their reactions in your diary, where appropriate.
- **DO NOT** use the MirrorCam Prototype in the presence of anyone who does not agree with you wearing the device. If someone confronts you about the prototype, explain what you are doing, and let them know that **the MirrorCam Prototype does not store any pictures persistently and does not record audio.** Be open towards their views. In all of these instances where the MirrorCam Prototype should not be used, please pause the study for the period of time in which you are in those situations or locations. **You should remove the device from your neck and put it in your pocket just to make sure that nobody suspects you of taking surreptitious images.**

E.2 Information Cards

All participants received a set of information cards to be handed out to third-parties inquiring about the study (including a link to FAQs).

CARL VON OSSIETZKY universität OLDENBURG — OFFIS INSTITUT FÜR INFORMATIK

This is a user study about how body-worn cameras could be designed to increase transparency and situation awareness for bystanders. The study is conducted by the Media Informatics and Multimedia Systems Group at the Department of Computing Science, University of Oldenburg in cooperation with OFFIS.

If you have any questions, please contact the researchers at studies@offis.de or view our FAQ at

http://www.staff.uni-oldenburg.de/marion.koelle/mirrorcam.html

Are there any pictures recorded by the prototype?

The prototype does not store any images persistently. This means that when the prototype's camera captures an image, the image is displayed on the integrated screen, but not saved. Any pixel data is deleted as soon as the image disappears from the screen.

Does the prototype record audio?

The prototype does not include a microphone and does not record audio.

This was given to you by participant #1

Figures

Tables

Bibliography

Papers included in the structured literature analysis presented in Section 2.2 are marked with labels in **boldface**.

[ACT+15] C. Ackad, A. Clayphan, M. Tomitsch, and J. Kay. An In-the-wild Study of Learning Mid-air Gestures to Browse Hierarchical Information at a Large Interactive Public Display. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'15)*, pages 1227–1238, New York, NY, USA. ACM, 2015.

[ASD+16] P. Aditya, R. Sen, P. Druschel, S. Joon Oh, R. Benenson, M. Fritz, B. Schiele, B. Bhattacharjee, and T. T. Wu. I-pic: A platform for Privacy-compliant Image Capture. In *Proceedings of the Conference on Mobile Systems, Applications, and Services (MobiSys'16)*, pages 235–248, 2016.

[ADL20] ADL, Anti-Defamation League. OK Hand Gesture, 2020. URL: `https://www.adl.org/education/references/hate-symbols/okay-hand-gesture` (visited on 06/01/2020).

[AM09] A. Agarwal and A. Meyer. Beyond Usability: Evaluating Emotional Response as an Integral Part of the User Experience. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'09)*, page 2919, New York, NY. ACM, 2009.

[AUK+15] H. Agrawal, U. Umapathi, R. Kovacs, J. Frohnhofen, H.-T. Chen, S. Mueller, and P. Baudisch. Protopiper: Physically Sketching Room-Sized Objects at Actual Scale. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'15)*, pages 427–436, New York, New York, USA. ACM Press, 2015.

[**AHI14**] D. Ahlström, K. Hasan, and P. Irani. Are You Comfortable Doing That?: Acceptance Studies of Around-device Gestures in and for Public Settings. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'14)*, pages 193–202, New York, NY, USA. ACM, 2014.

[AKP+18] T. Ahmed, A. Kapadia, V. Potluri, and M. Swaminathan. Up to a Limit?: Privacy Concerns of Bystanders and Their Willingness to Share Additional Information with Visually Impaired Users of Assistive Technologies. *PROC ACM IMWUT*, 2(3):1–27, 2018.

[ANS+18a] F. Alallah, A. Neshati, Y. Sakamoto, K. Hasan, E. Lank, A. Bunt, and P. Irani. Performer vs. Observer: Whose Comfort Level Should We Consider when Examining the Social Acceptability of Input Modalities for Head-worn Display? In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology (VRST'18)*, 10:1–10:9, 2018.

[ANS+18b] F. Alallah, A. Neshati, N. Sheibani, Y. Sakamoto, A. Bunt, P. Irani, and K. Hasan. Crowdsourcing vs Laboratory-Style Social Acceptability Studies?: Examining the Social Acceptability of Spatial User Interactions for Head-Worn Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, 310:1–310:7, New York, NY. ACM, 2018.

[ASV+18] R. Alharbi, T. Stump, N. Vafaie, A. Pfammatter, B. Spring, and N. Alshurafa. I Can't Be Myself: Effects of Wearable Cameras on the Capture of Authentic Behavior in the Wild. *PROC ACM IMWUT*, 2(3):90:1–90:40, 2018. URL: `http://doi.acm.org/10.1145/3264900`.

[AKE16] A. Alohali, K. Kunze, and R. Earle. Run with me: Designing Storytelling Tools for Runners. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'16)*, pages 5–8, New York, NY, USA. ACM, 2016.

[AGW+15] F. Anderson, T. Grossman, D. Wigdor, and G. Fitzmaurice. Supporting Subtlety with Deceptive Devices and Illusory Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 1489–1498, New York, NY. ACM, 2015.

[ACC+13] L. Angelini, M. Caon, S. Carrino, L. Bergeron, N. Nyffeler, M. Jean-Mairet, and E. Mugellini. Designing a Desirable Smart Bracelet for Older Adults. In *Adjunct Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing*, pages 425–434, New York, NY, USA. ACM, 2013.

[AEF+00] E. Arias, H. Eden, G. Fischer, A. Gorman, and E. Scharff. Transcending the Individual Human Mind – Creating Shared Understanding through Collaborative Design. *ACM T COMPUT-HUM INT*, 7(1):84–113, 2000.

[ASH+17] B. Ariel, A. Sutherland, D. Henstock, J. Young, P. Drover, J. Sykes, S. Megicks, and R. Henderson. "Contagious Accountability". *CRIM JUSTICE BEHAV*, 44(2):293–316, 2017.

[Art13] C. Arthur. Google Glass: Is it a Threat to our Privacy?, 6.03.2013. URL: `https://www.theguardian.com/technology/2013/mar/06/google-glass-threat-to-our-privacy` (visited on 08/15/2019).

[ABW17] M. Arvola, J. Blomkvist, and F. Wahlman. Lifelogging in User Experience Research: Supporting Recall and Improving Data Richness. *DES J*, 20(sup1):S3954–S3965, 2017.

[ANG+14] A. Ashok, V. Nguyen, M. Gruteser, N. Mandayam, W. Yuan, and K. Dana. Do not share!: Invisible Light Beacons for Signaling Preferences to Privacy-respecting Cameras. In *Proceedings of the ACM MobiCom Workshop on Visible Light Communication Systems (VLCS'14)*, pages 39–44, New York, NY, USA. ACM, 2014.

[APS12] O. Aubert, Y. Prié, and D. Schmitt. Advene as a Tailorable Hypervideo Authoring Tool. In *Proceedings of the ACM Symposium on Document Engineering*, page 79, New York, NY, USA. ACM Press, 2012.

[94] *Auditory Display: Sonification, Audification, and Auditory Interfaces*. G. Kramer, editor, volume 18. Addison-Wesley, Reading, Mass., 1994. URL: `http://www.loc.gov/catdir/enhancements/fy0830/94007975-b.html`.

[AF18] M. Avila Soto and M. Funk. Look, a Guidance Drone! Assessing the Social Acceptability of Companion Drones for Blind Travelers in Public Spaces. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'18)*, pages 417–419, New York, NY, USA. ACM, 2018.

[AFC16] S. Azenkot, C. Feng, and M. Cakmak. Enabling Building Service Robots to Guide Blind People: a Participatory Design Approach. In *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction (HCI'16)*, pages 3–10. IEEE, 2016.

[BMR+12] G. Bailly, J. Müller, M. Rohs, D. Wigdor, S. Kratz, L. G. Cowan, N. Weibel, W. G. Griswold, L. R. Pina, and J. D. Hollan. ShoeSense: A New Perspective on Gestural Interaction and Wearable Applications. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*, volume 16, pages 53–63, New York, NY. ACM, 2012.

[BKM08] A. Bangor, P. T. Kortum, and J. T. Miller. An Empirical Evaluation of the System Usability Scale. *INT J HUM-COMPUT INT*, 24(6):574–594, 2008.

[BWL+11] K. Barclay, D. Wei, C. Lutteroth, and R. Sheehan. A Quantitative Quality Model for Gesture Based User Interfaces. In *Proceedings of the Australasian Computer-Human Interaction Conference (OzCHI'11)*, pages 31–39, New York, NY. ACM, 2011.

[BQQ+11] M. S. Barhm, N. Qwasmi, F. Z. Qureshi, and K. el-Khatib. Negotiating Privacy Preferences in Video Surveillance Systems. In *Modern Approaches in Applied Intelligence*, pages 511–521, Berlin, Heidelberg. Springer Berlin Heidelberg, 2011.

[BC14a] L. Baruh and Z. Cemalcılar. It is More than Personal: Development and Validation of a Multidimensional Privacy Orientation Scale. *PERS INDIV DIFFER*, 70:165–170, 2014.

[BA11] T. Bekker and A. N. Antle. Developmentally Situated Design (DSD). In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, page 2531, New York, NY. ACM, 2011.

[BS93] V. Bellotti and A. Sellen. Design for Privacy in Ubiquitous Computing Environments. In *Proceedings of the European Conference on Computer Supported Cooperative Work (ECSCW'93)*, pages 77–92, Dordrecht. Kluwer Academic Publishers, 1993.

[Ber15] A. Berkley. Snapshot Seeing: Kodak Fiends, Child Photographers, and Henry James's What Maisie Knew. *MFS-MOD FICT STUD*, 61(3):375–403, 2015. URL: https://muse.jhu.edu/article/594732.

[BBV+19] T. Bipat, M. W. Bos, R. Vaish, and A. Monroy-Hernández. Analyzing the Use of Camera Glasses in the Wild. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, pages 1–8, New York, NY. ACM, 2019.

[BKD+08] D. Bitouk, N. Kumar, S. Dhillon, P. Belhumeur, and S. K. Nayar. Face Swapping: Automatically Replacing Faces in Photographs. *ACM T GRAPHIC*, 27(3):1, 2008.

[BSG89] M. M. Blattner, D. A. Sumikawa, and R. M. Greenberg. Earcons and Icons: Their Structure and Common Design Principles. *HUM-COMPUT INTERACT*, 4(1):11–44, 1989.

[BSL+14] C. Bo, G. Shen, J. Liu, X.-Y. Li, Y. Zhang, and F. Zhao. Privacy.tag: Privacy Concern Expressed and Respected. In *Proceedings of the ACM Conference on Embedded Network Sensor Systems (SenSys'14)*, pages 163–176, New York, NY, USA. ACM, 2014.

[Bød06] S. Bødker. When Second Wave HCI meets Third Wave Challenges. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'06)*, pages 1–8, New York, New York, USA. ACM Press, 2006.

[BDD+07] K. Boehner, R. DePaula, P. Dourish, and P. Sengers. How Emotion is Made and Measured. *International Journal of Human-Computer Studies*, 65(4):275–291, 2007.

[BCL+05] J. Bohn, V. Coroamă, M. Langheinrich, F. Mattern, and M. Rohs. Social, Economic, and Ethical Implications of Ambient Intelligence and Ubiquitous Computing. In W. Weber, J. M. Rabaey, and E. Aarts., editors, *Ambient Intelligence*, pages 5–29. Springer, Berlin, Germany, 2005.

[BKC19] S. Boll, M. Koelle, and J. Cauchard. Understanding the Socio-Technical Impact of Automated (Aerial) Vehicles on Casual Bystanders. In *Proceedings of the CHI 2019 Workshop on International workshop on Human-Drone Interaction*, Glasgow, Scotland, UK, 2019.

[BM12] A. Borning and M. Muller. Next Steps for Value Sensitive Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*, page 1125, New York, NY. ACM, 2012.

[BBG+19] A. Boucher, D. Brown, B. Gaver, N. Matsuda, L. Ovalle, A. Sheen, and M. Vanis. ProbeTools: Unconventional Cameras and Audio Devices for User Research. *Interactions*, 26(2):26–35, 2019.

[BBO+18] A. Boucher, D. Brown, L. Ovalle, A. Sheen, M. Vanis, W. Odom, D. Oogjes, and W. Gaver. TaskCam: Designing and Testing an Open Tool for Cultural Probes Studies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, pages 1–12, New York, NY. ACM, 2018.

[Bow12] J. Bowers. The logic of annotated portfolios. In *Proceedings of the Designing Interactive Systems Conference (DIS'12)*, page 68, New York, New York, USA. ACM Press and ACM, 2012.

[BL94] M. M. Bradley and P. J. Lang. Measuring Emotion: The Self-Assessment Manikin and the Semantic Differential. *J BEHAV THER EXP PSY*, 25(1):49–59, 1994.

[BMC+09] S. Brewster, R. Murray-Smith, A. Crossan, Y. Vasquez-Alvarez, and J. Rico. The GAIME Project: Gestural and Auditory Interactions for Mobile Environments. In *Whole Body Interaction Workshop*. ACM CHI 2019. `http://eprints.gla.ac.uk/34242/`, 2009.

[BC13] A. K. Bright and L. Coventry. Assistive Technology for Older Adults. In *Proceedings of the International Conference on Pervasive Technologies Related to Assistive Environments*, pages 1–4, New York, NY, USA. ACM, 2013.

[BC14b] M. Brocker and S. Checkoway. iSeeYou: Disabling the MacBook Webcam Indicator LED. In *USENIX Security Symposium*, pages 337–352, Berkeley, Calif. USENIX Association, 2014.

[BRS11] B. Brown, S. Reeves, and S. Sherwood. Into the Wild: Challenges and Opportunities for Field Trial Methods. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, page 1657, New York, NY. ACM, 2011.

[BBS17] N. A. Brown, A. B. Blake, and R. A. Sherman. A Snapshot of the Life as Lived: Wearable Cameras in Social and Personality Psychological Science. *SOC PSYCHOL PERS SCI*, 8(5):592–600, 2017.

[Bro08] T. Brown. Design Thinking. *HARVARD BUS REV*, 86(6):84, 2008.

[BK09] T. Brown and B. Kātz. *Change by design: How Design Thinking Transforms Organizations and Inspires Innovation*. Harper Business, New York, NY, 1. ed. Edition, 2009.

[BW10] T. Brown and J. Wyatt. Design Thinking for Social Innovation. *Development Outreach*, 12(1):29–43, 2010.

[BRK+16] A. Bruun, D. Raptis, J. Kjeldskov, and M. B. Skov. Measuring the Coolness of Interactive Products: the COOL Questionnaire. *BEHAV INFORM TECHNOL*, 35(3):233–249, 2016.

[BK13] C. Buenaflor and H.-C. Kim. Six Human Factors to Acceptability of Wearable Computers. *International Journal of Multimedia and Ubiquitous Engineering*, 8(3):1–8, 2013.

[BK16] A. Bulling and K. Kunze. Eyewear Computers for Human-Computer Interaction. *Interactions*, 23(3):70–73, 2016.

[BWG12] A. Bulling, J. A. Ward, and H. Gellersen. Multimodal Recognition of Reading Activity in Transit Using Body-worn Sensors. *ACM T APPL PERCEPT*, 9(1):1–21, 2012.

[BWG+11] A. Bulling, J. A. Ward, H. Gellersen, and G. Tröster. Eye Movement Analysis for Activity Recognition using Electrooculography. *IEEE T PATTERN ANAL*, 33(4):741–753, 2011.

[BWG13] A. Bulling, C. Weichel, and H. Gellersen. EyeContext: Recognition of High-level Contextual Cues from Human Visual Behaviour. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*, page 305, New York, NY. ACM, 2013.

[Cai09] K. E. Caine. *Exploring Everyday Privacy Behaviors and Misclosures*. PhD thesis, Georgia Institute of Technology, 2009.

[Cam07] S. W. Campbell. Perceptions of Mobile Phone Use in Public Settings: A Cross-cultural Comparison. *INT J COMMUN-US*, 1(1):20, 2007.

[CM15] D. Castro and A. McQuinn. *The Privacy Panic Cycle: A Guide to Public Fears About New Technologies*. The Information Technology & Innovation Foundation, Washington, DC, USA, 2015. URL: `http://www2.itif.org/2015-privacy-panic.pdf`.

[Cav09] A. Cavoukian. Privacy by Design – The 7 Foundational Principles, 2009. URL: `https://www.%20iab.%20org/wp-content/IAB-uploads/2011/03/fred%5Ctextunderscore%20carter.%20pdf`.

[CM17] L. Chan and K. Minamizawa. FrontFace: Facilitating Communication Between HMD Users and Outsiders Using Front-facing-screen HMDs. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'17)*, 22:1–22:5, New York, NY, USA. ACM, 2017.

[CTS+17] C.-M. Chang, K. Toda, D. Sakamoto, and T. Igarashi. Eyes on a Car. In *Proceedings of the International Conference on Automotive User Interfaces and Interactive Vehicular Applications (AutomotiveUI'17)*, pages 65–73, New York, New York, USA. ACM Press, 2017.

[CBK+11] D. M. Chen, G. Baatz, K. Koser, S. S. Tsai, R. Vedantham, T. Pylvanainen, K. Roimela, X. Chen, J. Bach, M. Pollefeys, B. Girod, and R. Grzeszczuk. City-scale Landmark Identification on Mobile Devices. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition*, pages 737–744. IEEE, 2011.

[CFT+19] Y.-T. Cheng, M. Funk, W.-C. Tsai, and L.-L. Chen. Peekaboo Cam: Designing an Observational Camera for Home Ecologies Concerning Privacy. In *Proceedings of the Designing Interactive Systems Conference (DIS'19)*, pages 823–836, New York, New York, USA. ACM Press, 2019.

[CNI+08] K. Chinomi, N. Nitta, Y. Ito, and N. Babaguchi. PriSurv: Privacy Protected Video Surveillance System Using Adaptive Visual Abstraction. In S. Satoh, F. Nack, and M. Etoh, editors, *Advances in Multimedia Modeling*. Volume 4903, pages 144–154. Springer Berlin Heidelberg, Berlin, Heidelberg, 2008.

[CFJ16] S. Chowdhury, M. S. Ferdous, and J. M. Jose. Bystander Privacy in Lifelogging. In *Proceedings of the BCS Human Computer Interaction Conference (BCS HCI'17)*. BCS, 2016.

[CEV+19] M. Chromik, M. Eiband, S. T. Völkel, and D. Buschek. Dark Patterns of Explainability, Transparency, and User Control for Intelligent Systems. In *Joint Proceedings of the ACM IUI Workshops co-located with the ACM Conference on Intelligent User Interfaces*, volume 2327, Aachen, Germany. CEUR Workshop Proceedings (CEUR-WS.org), 2019.

[CBH19] V. Cobus, S. Busse, and W. Heuten. Integration of Multimodal Alarms into Google Glass. In *Proceedings of the ACM International Symposium on Pervasive Displays (PerDis'19)*, pages 1–2, New York, New York, USA. ACM Press, 2019.

[Con16] C. Conrad. Deutsche Bahn testet Body-Cams, 2016. URL: `https://www.datenschutz-notizen.de/deutsche-bahn-testet-body-cams-4415298/` (visited on 08/15/2019).

[Con17] J. Constine. Why Snapchat Spectacles failed, 28.10.2017. URL: `https://techcrunch.com/2017/10/28/why-snapchat-spectacles-failed/` (visited on 08/15/2019).

[CSK+19] K. Copic Pucihar, C. Sandor, M. Kljun, W. Huerst, A. Plopski, T. Taketomi, H. Kato, and L. A. Leiva. The Missing Interface: Micro-Gestures on Augmented Objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, pages 1–6, New York, NY. ACM, 2019.

[CIA05] E. Costanza, S. A. Inverso, and R. Allen. Toward Subtle Intimate Interfaces for Mobile Devices Using an EMG Controller. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'05)*, pages 481–489, New York, NY. ACM, 2005.

[CIP+06] E. Costanza, S. A. Inverso, E. Pavlov, R. Allen, and P. Maes. Eye-q: Eyeglass Peripheral Display for Subtle Intimate Notifications. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'06)*, page 211, New York, New York, USA. ACM Press, 2006.

[Cra06] L. F. Cranor. What do they "indicate?": Evaluating Security and Privacy Indicators. *Interactions*, 13(3):45, 2006.

[CPT04] A. Criminisi, P. Perez, and K. Toyama. Region Filling and Object Removal by Exemplar-Based Image Inpainting. *IEEE T IMAGE PROCESS*, 13(9):1200–1212, 2004.

[Cro08] N. Cross. *Engineering Design Methods: Strategies for Product Design*. Wiley, Chichester, 4. ed. Edition, 2008. URL: `http://www.loc.gov/catdir/enhancements/fy0810/2008002727-d.html`.

[Czu17] S. Czupalla. *Exploration von Handgesten zur Mitteilung von Privatsphährepräferenzen im Sichtfeld von Datenbrillen*. Master's thesis, University of Oldenburg, Oldenburg, Germany, 2017.

[DKW+15] A. Dabrowski, K. Krombholz, E. R. Weippl, and I. Echizen. Smart Privacy Visor: Bridging the Privacy Gap. In W. Abramowicz, editor, *Business Information Systems Workshops*. Volume 228, pages 235–247. Springer International Publishing, Cham, 2015.

[DTB+02] T. Darrell, K. Tollmar, F. Bentley, N. Checka, L.-P. Morency, A. Rahimi, and A. Oh. Face-Responsive Interfaces: From Direct Manipulation to Perceptive Presence. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'02)*, volume 2498, pages 135–151, Berlin, Heidelberg. Springer Berlin Heidelberg, 2002.

[Dav86] F. D. Davis Jr. *A Technology Acceptance Model for Empirically Testing New End-user Information Systems: Theory and Results*. Ph.D. Dissertation, Massachusetts Institute of Technology, 1986. URL: `http://hdl.handle.net/1721.1/15192`.

[DW09] J. DeBlasio and B. N. Walker. Documentation in a Medical Setting. *PROC HUM FACT ERGON SOC ANNU MEET*, 53(11):645–649, 2009.

[DDK14] T. Denning, Z. Dehlawi, and T. Kohno. In Situ with Bystanders of Augmented Reality Glasses: Perspectives on Recording and Privacy-mediating Technologies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 2377–2386, New York, NY. ACM, 2014.

[DSN+18] C. Dierk, S. Sterman, M. J. P. Nicholas, and E. Paulos. HäirIÖ: Human Hair As Interactive Material. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction (TEI'18)*, pages 148–157, New York, NY, USA. ACM, 2018.

[Dix10] A. Dix. *Human-Computer Interaction*. Pearson Prentice-Hall, Harlow, 3. ed. Edition, 2010.

[DHR15] D. Dobbelstein, P. Hock, and E. Rukzio. Belt: An Unobtrusive Touch Input Device for Head-worn Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 2135–2138, New York, NY. ACM, 2015.

[DPC+12] A. R. Doherty, K. Pauly-Takacs, N. Caprani, C. Gurrin, C. J. A. Moulin, N. E. O'Connor, and A. F. Smeaton. Experiences of Aiding Autobiographical Memory Using the SenseCam. *HUM-COMPUT INTERACT*, 27(1-2):151–174, 2012.

[DGdL+04] P. Dourish, R. E. Grinter, J. de La Delgado Flor, and M. Joseph. Security in the Wild: User Strategies for Managing Security as an Everyday, Practical Problem. *PERS UBIQUIT COMPUT*, 8(6):391–401, 2004.

[DR01] A. Dunne and F. Raby. *Design Noir: The Secret Life of Electronic Objects*. Birkhäuser, Basel, 2001.

[DPZ+14] L. E. Dunne, H. Profita, C. Zeagler, J. Clawson, S. Gilliland, E. Y.-L. Do, and J. Budd. The Social Comfort of Wearable Technology and Gestural Interaction. In *Proceedings of the IEEE Engineering in Medicine and Biology Society (EMBC'14)*, pages 4159–4162, 2014.

[DGS+07] A. Dünser, R. Grasset, H. Seichter, and M. Billinghurst. Applying HCI Principles to AR Systems Design, 2007. URL: `http://ir.canterbury.ac.nz/bitstream/handle/10092/2340/12604890_2007-MRUI-Applying_HCI_principles.pdf`.

[EKC15] S. Egelman, R. Kannavara, and R. Chow. Is This Thing On?: Crowdsourcing Privacy Indicators for Ubiquitous Sensing Platforms. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 1669–1678, New York, NY. ACM, 2015.

[EPV+17] C. Eghtebas, Y. S. Pai, K. Väänänen, T. Pfeiffer, J. Meyer, and S. Lukosch. Initial Model of Social Acceptability for Human Augmentation Technologies. In *Proceedings of the CHI 2017 Workshop on Amplication and Augmentation of Human Perception*, Denver, CO, USA, 2017.

[EGA+15] B. Ens, T. Grossman, F. Anderson, J. Matejka, and G. Fitzmaurice. Candid Interaction: Revealing Hidden Mobile and Wearable Computing Activities. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'15)*, pages 467–476, New York, New York, USA. ACM Press, 2015.

[Era17] M. Erard. Why Sign-Language Gloves Don't Help Deaf People, 9.11.2017. URL: `https://www.theatlantic.com/technology/archive/2017/11/why-sign-language-gloves-dont-help-deaf-people/545441/` (visited on 08/15/2019).

[ECS14] Z. Erickson, J. Compiano, and R. Shin. Neural Networks for Improving Wearable Device Security. 2014. URL: `http://www.truststc.org/education/reu/14/Papers/Compiano_Erickson_Paper14.pdf`.

[ECK17] T. Euler, V. Cobus, and M. Koelle. Nummernschilder für Drohnen. *Datenschutz und Datensicherheit – DuD*, 41(3):147–151, 2017.

[Fal03] D. Fallman. Design-oriented Human-Computer Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'03)*, page 225, New York, NY. ACM, 2003.

[FH03] A. Field and G. Hole. *How to Design and Report Experiments*. Sage, 2003.

[Fla16] I. Flammer. Genteel Wearables: Bystander-Centered Design. *IEEE SECUR PRIV*, 14(5):73–79, 2016.

[FBL14] E. Freeman, S. Brewster, and V. Lantz. Towards Usable and Acceptable Above-device Interactions. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'14)*, pages 459–464, New York, NY, USA. ACM, 2014.

[Fri06] L. Frishberg. Presumptive Design, or Cutting the Looking-glass Cake. *Interactions*, 13(1):18, 2006.

[FRD+16] J. Frommel, K. Rogers, T. Dreja, J. Winterfeldt, C. Hunger, M. Bär, and M. Weber. 2084 Safe New World: Designing Ubiquitous Interactions. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play (CHI PLAY'16)*, pages 53–64, New York, NY, USA. ACM, 2016.

[GB12] B. Gaver and J. Bowers. Annotated portfolios. *Interactions*, 19(4):40, 2012.

[GDP99] B. Gaver, T. Dunne, and E. Pacenti. Design: Cultural Probes. *Interactions*, 6(1):21–29, 1999.

[GBV+19] W. Gaver, A. Boucher, M. Vanis, A. Sheen, D. Brown, L. Ovalle, N. Matsuda, A. Abbas-Nazari, and R. Phillips. My Naturewatch Camera: Disseminating Practice Research with a Cheap and Easy DIY Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, pages 1–13, New York, NY. ACM, 2019.

[GKS+98] F. Gemperle, C. Kasabach, J. Stivoric, M. Bauer, and R. Martin. Design for Wearability. In *Proceedings of the International Symposium on Wearable Computers (ISWC'98)*, pages 116–122, 1998.

[GC14a] V. Genaro Motti and K. Caine. Human Factors Considerations in the Design of Wearable Devices. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 58(1):1820–1824, 2014.

[GC14b] V. Genaro Motti and K. Caine. Understanding the Wearability of Head-mounted Devices from a Human-centered Perspective. In *Proceedings of the International Symposium on Wearable Computers (ISWC'14)*, pages 83–86, New York, NY, USA. ACM, 2014.

[Gla79] D. J. Glancy. The Invention of the Right to Privacy. *ARIZONA LAW REVIEW*, 21, 1979.

[GSF+16] J. Gluck, F. Schaub, A. Friedman, H. Habib, N. Sadeh, L. F. Cranor, and Y. Agarwal. How Short Is Too Short? Implications of Length and Framing on the Effectiveness of Privacy Notices. In *Proceedings of the Symposium on Usable Privacy and Security*. USENIX Association, 2016.

[Gof59] E. Goffman. *The Presentation of Self in Everyday Life*. Doubleday, New York, NY, 1959.

[GLV+17] J. Gong, L. Li, D. Vogel, and X.-D. Yang. Cito: An Actuated Smartwatch for Extended Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'17)*, pages 5331–5345, New York, NY. ACM, 2017.

[Goo20] L. Goode. OnePlus Shows Off a Phone With a Disappearing Rear Camera, 1.03.2020. URL: `https://www.wired.com/story/oneplus-concept-one/` (visited on 08/15/2019).

[GTK+12] M. Granados, J. Tompkin, K. Kim, O. Grau, J. Kautz, and C. Theobalt. How Not to Be Seen - Object Removal from Videos of Crowded Scenes. *COMPUT GRAPH FORUM*, 31(2pt1):219–228, 2012.

[GKB+18] C. M. Gray, Y. Kou, B. Battles, J. Hoggatt, and A. L. Toombs. The Dark (Patterns) Side of UX Design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, pages 1–14, New York, NY. ACM, 2018.

[GBV+14] S. Greenberg, S. Boring, J. Vermeulen, and J. Dostal. Dark Patterns in Proxemic Interactions: a Critical Perspective. In *Proceedings of the Conference on Designing interactive systems (DIS'14)*, pages 523–532, New York, New York, USA. ACM Press, 2014.

[GCM+13] S. Greenberg, S. Carpendale, N. Marquardt, and B. Buxton. *Sketching User Experiences – The Workbook*. Elsevier Morgan Kaufmann, Amsterdam, 2013.

[GFC+09] R. M. Groves, F. J. Fowler Jr, M. P. Couper, J. M. Lepkowski, E. Singer, and R. Tourangeau. *Survey Methodology*, volume 561. John Wiley & Sons, 2009.

[GL00] E. G. Guba and Y. S. Lincoln. Competing Paradigms in Qualitative Research. In N. K. Denzin and Y. S. Lincoln, editors, *Handbook of Qualitative Research*. Volume 2, pages 105–117. Sage Publ, Thousand Oaks, 2000.

[GSS+18] J. Gugenheimer, E. Stemasov, H. Sareen, and E. Rukzio. FaceDisplay: Towards Asymmetric Multi-User Interaction for Nomadic Virtual Reality. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, 54:1–54:13, New York, NY. ACM, 2018.

[GAJ+14] C. Gurrin, R. Albatal, H. Joho, and K. Ishii. A Privacy by Design Approach to Lifelogging. *Digital Enlightenment Yearbook*:49–73, 2014. URL: `http://doras.dcu.ie/20505/`.

[GBG+08] S. Gustafson, P. Baudisch, C. Gutwin, and P. Irani. Wedge: Clutter-free Visualization of off-screen Locations. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'08)*, pages 787–796, New York, NY. ACM, 2008.

[HVC+15] J. Häkkilä, F. Vahabpour, A. Colley, J. Väyrynen, and T. Koskela. Design Probes Study on User Perceptions of a Smart Glasses Concept. In *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia (MUM'15)*, pages 223–233, New York, NY, USA. ACM, 2015.

[HHH+12] C. Harrison, J. Horstman, G. Hsieh, and S. Hudson. Unlocking the Expressivity of Point Lights. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*, page 1683, New York, NY. ACM, 2012.

[Har06] S. G. Hart. Nasa-Task Load Index (NASA-TLX); 20 Years Later. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 50(9):904–908, 2006.

[Har10] A. Harvey. Camoflash: Anti-Paparazzi Clutch, 2010. URL: `http://ahprojects.%20com/projects/camoflash/`.

[Har12] A. Harvey. CV Dazzle: Camouflage from Computer Vision. *Technical report*, 2012. URL: `https://cvdazzle.com/`.

[HCS15] J. A. Harvey, S. F. M. Chastin, and D. A. Skelton. How Sedentary are Older People? A Systematic Review of the Amount of Sedentary Behavior. *J AGING PHYS ACTIV*, 23(3):471–487, 2015.

[HSC16] J. A. Harvey, D. A. Skelton, and S. F. M. Chastin. Acceptability of Novel Life Logging Technology to Determine Context of Sedentary Behavior in Older Adults. *AIMS public health*, 3(1):158–171, 2016.

[Has04] M. Hassenzahl. The Interplay of Beauty, Goodness, and Usability in Interactive Products. *HUM-COMPUT INTERACT*, 19(4):319–349, 2004.

[Has08] M. Hassenzahl. User experience (UX): towards an experiential perspective on product quality. In *Proceedings of the International Conference of the Association Francophone d'Interaction Homme-Machine (IHM'08)*, page 11, New York, NY, USA. ACM, 2008.

[HM10] M. Hassenzahl and A. Monk. The Inference of Perceived Usability From Beauty. *HUM-COMPUT INTERACT*, 25(3):235–260, 2010.

[HPB+00] M. Hassenzahl, A. Platz, M. Burmester, and K. Lehner. Hedonic and Ergonomic Quality Aspects Determine a Software's Appeal. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'00)*, pages 201–208, New York, NY. ACM, 2000.

[Has10] Hasso Plattner Institute. An Introduction to Design Thinking: Process Guide. *The Institute of Design at Stanford: Stanford*, 2010.

[HOW+18] S. Hauser, D. Oogjes, R. Wakkary, and P.-P. Verbeek. An Annotated Portfolio on Doing Postphenomenology Through Research Products. In *Proceedings of the Designing Interactive Systems Conference (DIS'18)*, pages 459–471, New York, New York, USA. ACM Press, 2018.

[HSS13] B. Henne, C. Szongott, and M. Smith. SnapMe if you can: Privacy Threats of other Peoples' Geo-tagged Media and what we can do about it. In *Proceedings of the ACM Conference on Security and Privacy in Wireless and Mobile Networks*, page 95, New York, New York, USA. ACM Press, 2013.

[HK17] N. Henze and K. Kunze. A Dagstuhl Seminar Looks beyond Virtual and Augmented Reality. *IEEE MultiMedia*, 24(2):14–17, 2017.

[HLB+10] N. Henze, A. Löcken, S. Boll, T. Hesselmann, and M. Pielot. Free-hand Gestures for Music Playback: Deriving Gestures with a User-centred Process. In *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia (MUM'10)*, 16:1–16:10, New York, NY. ACM, 2010.

[Hig94] J. M. Higgins. *101 Creative Problem Solving Techniques: The Handbook of new Ideas for Business*. New Management Publishing Company, 1994.

[Hig96] J. M. Higgins. Innovate or Evaporate: Creative Techniques for Strategists. *LONG RANGE PLANN*, 29(3):370–380, 1996.

[HS18] A. Hirst and C. Schwabenland. Doing Gender in the 'New Office'. *GENDER WORK ORGAN*, 25(2):159–176, 2018.

[HWB+06] S. Hodges, L. Williams, E. Berry, S. Izadi, J. Srinivasan, A. Butler, G. Smyth, N. Kapur, and K. Wood. SenseCam: A Retrospective Memory Aid. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'06)*, volume 4206, pages 177–193, Berlin, Heidelberg. Springer Berlin Heidelberg, 2006.

[Hoe18] T. Hoeren. Anmerkung zu Landgericht Frankfurt/Main, Urteil vom 13.9.2018. *Zeitschrift für Datenschutz*:587–588, 2018.

[HSP+08] P. Holleis, A. Schmidt, S. Paasovaara, A. Puikkonen, and J. Häkkilä. Evaluating Capacitive Touch Input on Clothes. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'08)*, pages 81–90, New York, NY, USA. ACM, 2008.

[Hol05] L. E. Holmquist. Prototyping: Generating Ideas or Cargo Cult Designs? *Interactions*, 12(2):48, 2005.

[HW17] C. Holz and E. J. Wang. Glabella: Continuously Sensing Blood Pressure Behavior Using an Unobtrusive Wearable Device. *PROC ACM IMWUT*, 1(3):58:1–58:23, 2017. URL: http://doi.acm.org/10.1145/3132024.

[HLM+18] S. Hoppe, T. Loetscher, S. A. Morey, and A. Bulling. Eye Movements During Everyday Behavior Predict Personality Traits. *FRONT HUM NEUROSCI*, 12:105, 2018.

[HH17] K. Hornbæk and M. Hertzum. Technology Acceptance and User Experience: A Review of the Experiential Component in HCI. *ACM T COMPUT-HUM INT*, 24(5):1–30, 2017.

[HN12] E. Hornecker and E. Nicol. What do Lab-based User Studies tell us about In-the-wild Behavior? In *Proceedings of the Designing Interactive Systems Conference (DIS'12)*, page 358, New York, New York, USA. ACM Press and ACM, 2012.

[Hos84] S. Hosokawa. The Walkman Effect. *POP MUSIC*, 4:165–180, 1984.

[HOK+13] B. Hou, H. Ogata, T. Kunita, M. Li, and N. Uosaki. PACALL: Supporting Language Learning Using SenseCam. *International Journal of Distance Education Technologies*, 11(1):14–30, 2013.

[HH97] S. Houde and C. Hill. What do Prototypes Prototype? In M. Helander, T. K. Landauer, and P. V. Prabhu, editors, *Handbook of Human-Computer Interaction*, pages 367–381. Elsevier, Amsterdam and New York, 1997.

[HIC+15] R. Hoyle, Q. Ismail, D. Crandall, and A. Kapadia. Challenges in Running Wearable Camera-Related User Studies. In *The Future of Networked Privacy: Challenges and Opportunities. CSCW Companion.* Vancouver, BC, Canada, 2015.

[HTA+14] R. Hoyle, R. Templeman, S. Armes, D. Anthony, D. Crandall, and A. Kapadia. Privacy Behaviors of Lifeloggers Using Wearable Cameras. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'14)*, pages 571–582, New York, NY, USA. ACM, 2014.

[HJO+16] Y.-T. Hsieh, A. Jylhä, V. Orso, L. Gamberini, and G. Jacucci. Designing a Willing-to-Use-in-Public Hand Gestural Interaction Technique for Smart Glasses. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, pages 4203–4215, New York, NY. ACM, 2016.

[HHR+03] H. Hutchinson, H. Hansen, N. Roussel, B. Eiderbäck, W. Mackay, B. Westerlund, B. B. Bederson, A. Druin, C. Plaisant, M. Beaudouin-Lafon, S. Conversy, and H. Evans. Technology Probes: Inspiring Design for and with Families. In *Proceedings of the SIGCHI Confer-*

ence on Human Factors in Computing Systems (CHI'03), page 17, New York, NY. ACM, 2003.

[ITA+06] G. Iachello, K. N. Truong, G. D. Abowd, G. R. Hayes, and M. Stevens. Prototyping and Sampling Experience to Evaluate Ubiquitous Computing Privacy in the Real World. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'06)*, page 1009, New York, NY. ACM, 2006.

[IDE15] IDEO.org. *The Field Guide to Human-Centered Design: Design kit.* IDEO, San Francisco, Calif., 1st. ed. Edition, 2015.

[ISO19] ISO, International Organization for Standardization. ISO 9241-210: Ergonomics of Human-system Interaction – Part 210: Human-centred Design for Interactive Systems, 2019. URL: `https://www.iso.org/standard/77520.html` (visited on 08/15/2019).

[JMO+16] P. Jarusriboonchai, A. Malapaschas, T. Olsson, and K. Väänänen. Increasing Collocated People-s Awareness of the Mobile User-s Activities: a Field Trial of Social Displays. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW'16)*, pages 1689–1700, New York, NY, USA. ACM Press, 2016.

[JOV14] P. Jarusriboonchai, T. Olsson, and K. Väänänen-Vainio-Mattila. User Experience of Proactive Audio-based Social Devices: A Wizard-of-oz Study. In *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia (MUM'14)*, pages 98–106, New York. ACM, 2014.

[JCB12] N. Jarvis, D. Cameron, and A. Boucher. Attention to detail. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'12)*, page 11, New York, New York, USA. ACM Press, 2012.

[JLF15] W. G. Jennings, M. D. Lynch, and L. A. Fridell. Evaluating the impact of police officer body-worn cameras (BWCs) on response-to-resistance and serious external complaints: Evidence from the Orlando police department (OPD) experience utilizing a randomized controlled experiment. *J CRIM JUST*, 43(6):480–486, 2015.

[JSG+07] W. Jones, J. Spool, J. Grudin, V. Bellotti, and M. Czerwinski. "Get Real!": What's wrong with HCI Prototyping and how can we fix it? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'07)*, page 1913, New York, NY, USA. ACM, 2007.

[JP14] J. Jung and M. Philipose. Courteous Glass. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'14)*, pages 1307–1312, New York, NY, USA. ACM, 2014.

[KSC99] E. Karahanna, D. W. Straub, and N. L. Chervany. Information Technology Adoption Across Time: A Cross-sectional Comparison of Pre-adoption and Post-adoption Beliefs. *MIS Q*, 23(2):183–213, 1999. URL: http://dx.doi.org/10.2307/249751.

[Ksm05] M. Karam and m. schraefel mc. A Taxonomy of Gestures in Human Computer Interaction, 2005. URL: https://eprints.soton.ac.uk/id/eprint/261149.

[KGC+09] K. Karrer, C. Glaser, C. Clemens, and C. Bruder. Technikaffinität Erfassen — der Fragebogen TA-EG [Assessing Technical Affinity – the Questionnaire TA-EG]. In A. Lichtenstein, editor, *Der Mensch im Mittelpunkt technischer Systeme*. Volume 8, pages 196–201. VDI-Verl., Düsseldorf, 2009.

[KWL+11] T. Karrer, M. Wittenhagen, L. Lichtschlag, F. Heller, and J. Borchers. Pinstripe: Eyes-free Continuous Input on Interactive Clothing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, pages 1313–1322, New York, NY. ACM, 2011.

[KPB14] M. Kassner, W. Patera, and A. Bulling. Pupil: an Open Source Platform for Pervasive Eye Tracking and Mobile Gaze-based Interaction. In *Adjunct Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'14 Adjunct)*, pages 1151–1160, New York, NY, USA. ACM, 2014.

[KCS13] P. G. Kelley, L. F. Cranor, and N. Sadeh. Privacy as Part of the App Decision-making Process. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*, page 3393, New York, NY. ACM, 2013.

[Kel13] H. Kelly. Google Glass Users Fight Privacy Fears, 10.12.2013. URL: https://www.cnn.com/2013/12/10/tech/mobile/negative-google-glass-reactions/index.html (visited on 08/15/2019).

[KG16] N. Kelly and S. Gilbert. The WEAR Scale: Developing a Measure of the Social Acceptability of a Wearable Device. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, pages 2864–2871, New York, NY. ACM, 2016.

[Ken86] A. Kendon. Current Issues in the Study of Gesture. In J.-L. Nespoulous, P. Perron, and A. R. Lecours, editors, *The Biological Foundations of Gestures: Motor and Semiotic Acpects*, pages 23–47. Lawrence Erlbaum Associates, 1986.

[KKL+17] F. Kerber, T. Kiefer, M. Löchtefeld, and A. Krüger. Investigating Current Techniques for Opposite-hand Smartwatch Interaction. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (Mobile-HCI'17)*, pages 1–12, New York, NY, USA. ACM, 2017.

[Kim15] H.-C. Kim. Acceptability Engineering: The Study of user Acceptance of Innovative Technologies. *J APPL RES TECHNOL*, 13(2):230–237, 2015.

[KSP+06] S. Kim, M. Sohn, J. Pak, and W. Lee. One-key Keyboard: A Very Small QWERTY Keyboard Supporting Text Entry for Wearable Computing. In *Proceedings of the Australasian Computer-Human Interaction Conference (OzCHI'06)*, pages 305–308, New York, NY, USA. ACM, 2006.

[KG15] R. Kirkham and C. Greenhalgh. Social Access vs. Privacy in Wearable Computing: A Case Study of Autism. *IEEE PERVAS COMPUT*, 14(1):26–33, 2015.

[KP12] J. Kjeldskov and J. Paay. A Longitudinal Review of Mobile HCI Research Methods. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'12)*, page 69, New York, New York, USA. ACM Press, 2012.

[KS14] J. Kjeldskov and M. B. Skov. Was it worth the hassle? Ten Years of Mobile HCI Research Discussions on Lab and Field Evaluations. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'14)*, pages 43–52, New York, NY, USA. ACM, 2014.

[KSA+04] J. Kjeldskov, M. B. Skov, B. S. Als, and R. T. Høegh. Is It Worth the Hassle? Exploring the Added Value of Evaluating the Usability of Context-Aware Mobile Systems in the Field. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, S. Brewster, and M. Dunlop, editors, *Proceedings of the International Conference on Mobile Human-Computer Interaction (MobileHCI'04)*. Volume 3160, pages 61–73. Springer Berlin Heidelberg, Berlin, Heidelberg, 2004.

[Kla12] M. Klar. *Datenschutzrecht und die Visualisierung des öffentlichen Raums: Zugl.: Regensburg, Univ., Diss., 2012*, volume 23. LIT, Berlin, 2012.

[KSP+05] J. F. Knight, A. Schwirtz, F. Psomadelis, C. Baber, H. W. Bristow, and T. N. Arvanitis. The Design of the SensVest. *PERS UBIQUIT COMPUT*, 9(1):6–19, 2005.

[Koe19] M. Koelle. Privacy Mediation Cards. S. Boll, editor, 2019. to appear.

[KAB20] M. Koelle, S. Ananthanarayan, and S. Boll. Social Acceptability in HCI: A Survey of Methods, Measures, and Design Strategies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 1–19, Honolulu, HI, USA. ACM, 2020.

[KAC+18] M. Koelle, S. Ananthanarayan, S. Czupalla, W. Heuten, and S. Boll. Your Smart Glasses' Camera Bothers Me!: Exploring Opt-in and Opt-out Gestures for Privacy Mediation. In *Proceedings of the Nordic Conference on Human-Computer Interaction*, pages 473–481, New York, NY, USA. ACM, 2018.

[KB19] M. Koelle and S. Boll. The Privacy Mediation Cards – A Participatory Design Approach towards Respectful Smart Glasses. In *Proceedings of the CHI 2019 Workshop on Challenges Using Head-Mounted Displays in Shared and Social Spaces*, Glasgow, Scotland, UK, 2019.

[KBC+17] M. Koelle, Y. Brück, V. Cobus, W. Heuten, and S. Boll. Respektvolle tragbare Kameras? – Technische Gestaltung einer sozialakzeptablen Nutzung von Datenbrillen und Smart Cams. *Datenschutz und Datensicherheit – DuD*, 41(3):152–158, 2017.

[KEC+17] M. Koelle, A. El Ali, V. Cobus, W. Heuten, and S. Boll. All about Acceptability?: Identifying Factors for the Adoption of Data Glasses. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 295–300, New York, NY, USA. ACM, 2017.

[KGS+19] M. Koelle, C. George, V. Schwind, D. Perry, Y. Sakamoto, K. Hasan, R. Mitchell, and T. Olsson. #SociallyAcceptableHCI: Social Acceptability of Emerging Technologies and Novel Interaction Paradigms. In *Proceedings of the IFIP Conference on Human-Computer Interaction*. Springer, 2019.

[KHB17] M. Koelle, W. Heuten, and S. Boll. Are you hiding it?: Usage Habits of Lifelogging Camera Wearers. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services*, 80:1–80:8, New York, NY, USA. ACM, 2017.

[KKM15] M. Koelle, M. Kranz, and A. Möller. Don't look at me that way!: Understanding User Attitudes Towards Data Glasses Usage. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services*, pages 362–372, New York, NY, USA. ACM, 2015.

[KOM+19] M. Koelle, T. Olsson, R. Mitchell, J. Williamson, and S. Boll. What is (Un)Acceptable?: Thoughts on Social Acceptability in HCI Research. *Interactions*, 26(3):36–40, April 2019. URL: `http://doi.acm.org/10.1145/3319073`.

[KOW+18] M. Koelle, T. Olsson, J. Williamson, H. Profita, S. Kane, R. Mitchell, and S. Boll. (Un)Acceptable!?!: Re-thinking the Social Acceptability of Emerging Technologies. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, W03:1–W03:8, New York, NY, USA. ACM, 2018.

[KRB19] M. Koelle, E. Rose, and S. Boll. Ubiquitous Intelligent Cameras – Between Legal Nightmare and Social Empowerment. *IEEE MULTIMEDIA*, 26(2):76–86, April 2019.

[KWH+19] M. Koelle, T. Wallbaum, W. Heuten, and S. Boll. Evaluating a Wearable Camera's Social Acceptability In-the-Wild. In *Extended Abstracts of the SIGCHI Conference on Human Factors in Computing Systems*, LBW1222:1–LBW1222:6, New York, NY, USA. ACM, 2019.

[KWB18] M. Koelle, K. Wolf, and S. Boll. Beyond LED Status Lights - Design Requirements of Privacy Notices for Body-worn Cameras. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction*, pages 177–187, New York, NY, USA. ACM, 2018.

[KTC+14] M. Korayem, R. Templeman, D. Chen, D. Crandall, and A. Kapadia. Screenavoider: Protecting Computer Screens from Ubiquitous Cameras. *arXiv preprint arXiv:1412.0008*, 2014.

[KTC+16] M. Korayem, R. Templeman, D. Chen, D. Crandall, and A. Kapadia. Enhancing Lifelogging Privacy by Detecting Screens. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, pages 4309–4314, New York, NY. ACM, 2016.

[KDS+15] K. Krombholz, A. Dabrowski, M. Smith, and E. Weippl. Ok Glass, Leave Me Alone: Towards a Systematization of Privacy Enhancing Technologies for Wearable Computing. In M. Brenner, N. Christin, B. Johnson, and K. Rohloff, editors, *Financial Cryptography and Data Security*. Volume 8976, pages 274–280. Springer Berlin Heidelberg, Berlin, Heidelberg, 2015.

[KDS+17] K. Krombholz, A. Dabrowski, M. Smith, and E. Weippl. Exploring Design Directions for Wearable Privacy. In *Proceedings of the Workshop on Usable Security (USEC'17)*, Reston, VA. Internet Society, 2017.

[KB14] V. Kuchelmeister and J. Bennet. The Amnesia Atlas. An immersive SenseCam interface as memory-prosthesis. In *Proceedings of the International Conference on Virtual Systems & Multimedia (VSMM'14)*, pages 217–222. IEEE, 2014.

[Kun55] T. Kunin. The Construction of a New Type of Attitude Measure. *PERS PSYCHOL*, 8(1):65–77, 1955.

[LC19] C. Lacey and C. Caudwell. Cuteness as a ‘Dark Pattern’ in Home Robots. In *ACM/IEEE International Conference on Human-Robot Interaction (HRI’19)*, pages 374–381. IEEE, 2019.

[LK77] J. R. Landis and G. G. Koch. The Measurement of Observer Agreement for Categorical Data. *Biometrics*, 33(1):159, 1977.

[Lan01] M. Langheinrich. Privacy by Design – Principles of Privacy-aware Ubiquitous Systems. In *Proceedings of the International Conference on Ubiquitous Computing*, pages 273–291, Berlin, Heidelberg. Springer Berlin Heidelberg, 2001.

[LC14] R. Larson and M. Csikszentmihalyi. The Experience Sampling Method. In M. Csikszentmihalyi, editor, *Flow and the Foundations of Positive Psychology*, pages 21–34. Springer Netherlands, Dordrecht, 2014.

[LH17] A. Lauber-Rönsberg and A. Hartlaub. Personenbildnisse im Spannungsfeld zwischen Äußerungs-und Datenschutzrecht. *Neue Juristische Wochenschrift: NJW*, 70(15):1057–1061, 2017.

[LHF17] J. Lazar, H. Hochheiser, and J. H. Feng. *Research Methods in Human-Computer Interaction*. Morgan Kaufmann, Cambridge, MA, second edition edition, 2017. URL: `http://proquest.tech.safaribooksonline.de/9780128093436`.

[LLS+18] D. Lee, Y. Lee, Y. Shin, and I. Oakley. Designing Socially Acceptable Hand-to-Face Input. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST’18)*, pages 711–723, New York, NY, USA. ACM, 2018.

[LŠC+17] H. R. Lee, S. Šabanović, W.-L. Chang, S. Nagata, J. Piatt, C. Bennett, and D. Hakken. Steps Toward Participatory Design of Social Robots. In *Proceedings of the ACM/IEEE International Conference on Human-Robot Interaction (HRI’17)*, pages 244–253, New York, NY, USA. ACM Press, 2017.

[LBT02] S. Lenman, L. Bretzner, and B. Thuresson. Using Marking Menus to Develop Command Sets for Computer Vision Based Hand Gesture Interfaces. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI’02)*, pages 239–242, New York, NY. ACM, 2002.

[LP14] D. J. Liebling and S. Preibusch. Privacy Considerations for a Pervasive Eye Tracking World. In *Adjunct Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp’14 Adjunct)*, pages 1169–1177, New York, NY, USA. ACM, 2014.

[Lik32] R. Likert. A Technique for the Measurement of Attitudes. *ARCH PSYCHOL*, 22(140):5–53, 1932.

[LPP+06] Y.-K. Lim, A. Pangam, S. Periyasami, and S. Aneja. Comparative Analysis of High- and Low-fidelity Prototypes for more Valid Usability Evaluations of Mobile Devices. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'06)*, pages 291–300, New York, New York, USA. ACM Press, 2006.

[LST08] Y.-K. Lim, E. Stolterman, and J. Tenenberg. The Anatomy of Prototypes: Prototypes as Filters, Prototypes as Manifestations of Design Ideas. *ACM T COMPUT-HUM INT*, 15(2):1–27, 2008.

[LXD+19] A. Liu, L. Xia, A. Duchowski, R. Bailey, K. Holmqvist, and E. Jain. Differential Privacy for Eye-tracking Data. In *Proceedings of the ACM Symposium on Eye Tracking Research & Applications (ETRA'19)*, pages 1–10, New York, NY, USA. ACM Press, 2019.

[Loe01] K. M. Loewenthal. *An Introduction to Psychological Tests and Scales (2nd Edition)*. Psychology Press, New York, NY, USA, 2001.

[LBW+17] D. Lottridge, F. Bentley, M. Wheeler, J. Lee, J. Cheung, K. Ong, and C. Rowley. Third-wave Livestreaming: Teens' Long Form Selfie. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'17)*, pages 1–12, New York, NY, USA. ACM, 2017.

[Lov18] J. Lovejoy. The UX of AI: Using Google Clips to Understand How a Human-Centered Design Process Elevates Artificial Intelligence. In *Proceedings of the AAAI Spring Symposium Series*, 2018.

[LV14] A. Lucero and A. Vetek. NotifEye: Using Interactive Glasses to Deal with Notifications While Walking in Public. In *Proceedings of the Conference on Advances in Computer Entertainment Technology (ACE'14)*, 17:1–17:10, New York, NY, USA. ACM, 2014.

[LSC+09] H. C. Lum, V. K. Sims, M. G. Chin, and N. C. Lagattuta. Perceptions of Humans Wearing Technology. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 53(13):864–868, 2009.

[LHF+15] Z. Lv, A. Halawani, S. Feng, S. Ur Réhman, and H. Li. Touch-less Interactive Augmented Reality Game on Vision-based Wearable Device. *PERS UBIQUIT COMPUT*, 19(3-4):551–567, 2015. URL: `http://dx.doi.org/10.1007/s00779-015-0844-1`.

[LHL+13] Z. Lv, A. Halawani, M. S. Lal Khan, S. U. Réhman, and H. Li. Finger in Air: Touch-less Interaction on Smartphone. In *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia (MUM'13)*, 16:1–16:4, New York, NY, USA. ACM, 2013.

[MSL+16] D. Machuletz, H. Sendt, S. Laube, and R. Böhme. Users Protect Their Privacy If They Can: Determinants of Webcam Covering Behavior. In *Proceedings of the European Workshop on Usable Security at the Privacy Enhaning Technologies Symposium (EuroSEC'16)*, Reston, VA. Internet Society, 2016.

[MG99] Y. Malhotra and D. F. Galletta. Extending the Technology Acceptance Model to Account for Social Influence: Theoretical Bases and Empirical Validation. In *Proceedings of the Annual Hawaii International Conference on System Sciences (HICSS'99)*, pages 1006–1019, Washington, DC, USA. IEEE Computer Society, 1999.

[Man00] S. Mann. Telepointer: Hands-free completely self-contained wearable visual augmented reality without headwear and without any infrastructural reliance. In *Proceedings of the International Symposium on Wearable Computers (ISWC'00)*, pages 177–178. IEEE Computer Society, 2000.

[Man97] S. Mann. Wearable Computing: A First Step toward Personal Imaging. *Computer*, 30(2):25–32, 1997.

[Man04] S. Mann. "Sousveillance": Inverse Surveillance in Multimedia Imaging. In *Proceedings of the annual ACM International Conference on Multimedia*, page 620, New York, NY, USA. ACM Press, 2004.

[Man13] S. Mann. Wearable Computing. *The Encyclopedia of Human-Computer Interaction, 2nd Ed*, 2013.

[Man14] S. Mann. The Sightfield: Visualizing Computer Vision, and Seeing Its Capacity to "See. In *The IEEE Conference on Computer Vision and Pattern Recognition Workshops (CVPR'14)*, 2014.

[Man16] S. Mann. Veillance Integrity by Design: A new Mantra for CE Devices and Services. *IEEE CONSUM ELEC MAG*, 5(1):33–143, 2016.

[MSC+09] J. Manweiler, R. Scudellari, Z. Cancio, and L. P. Cox. We Saw Each Other on the Subway: Secure, Anonymous Proximity-based Missed Connections. In *Proceedings of the Workshop on Mobile Computing Systems and Applications*, pages 1–6, New York, NY, USA. ACM Press, 2009.

[MW00] T. Marsh and P. Wright. Using Cinematography Conventions to Inform Guidelines for the Design and Evaluation of Virtual Offscreen Space. In *Smart Graphics; Papers from the 2000 AAAI Spring Symposium, Technical Report (SS-00-04)*, pages 123–127, Menlo Park, Calif. AAAI Press, 2000.

[MMR+11] P. Marshall, R. Morris, Y. Rogers, S. Kreitmayer, and M. Davies. Rethinking 'multi-user': an In-the-wild Study of How Groups Approach a Walk-up-and-use Tabletop Interface. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, page 3033, New York, NY. ACM, 2011.

[MSO+16] K. Masai, Y. Sugiura, M. Ogata, K. Kunze, M. Inami, and M. Sugimoto. Facial Expression Recognition in Daily Life by Embedded Photo Reflective Sensors on Smart Eyewear. In *Proceedings of the International Conference on Intelligent User Interfaces (IUI'16)*, pages 317–326, New York, NY, USA. ACM, 2016.

[MdLS11] M.-E. Maurer, A. de Luca, and T. Stockinger. Shining Chrome: Using Web Browser Personas to Enhance SSL Certificate Visualization. In *Proceedings of the IFIP Conference on Human-Computer Interaction (INTERACT'11)*, volume 6949, pages 44–51. Springer, 2011.

[May14] P. Mayring. Qualitative Content Analysis: Theoretical Foundation, Basic Procedures and Software Solution, 2014. URL: `http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173`.

[MP06] G. McAtamney and C. Parker. An Examination of the Effects of a Wearable Display on Informal Face-to-Face Communication. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'06)*, page 45, New York, NY. ACM, 2006.

[MG01] A. T. McCray and M. E. Gallagher. Principles for digital library development. *COMMUN ACM*, 44(5):48–54, May 2001. URL: `https://doi.org/10.1145/374308.374339`.

[MVR+14] R. McNaney, J. Vines, D. Roggen, M. Balaam, P. Zhang, I. Poliakov, and P. Olivier. Exploring the Acceptability of Google Glass as an Everyday Assistive Device for People with Parkinson's. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 2551–2554, New York, NY. ACM, 2014.

[MLL+11] R. McNaney, S. Lindsay, K. Ladha, C. Ladha, G. Schofield, T. Ploetz, N. Hammerla, D. Jackson, R. Walker, N. Miller, and P. Olivier. Cueing for Drooling in Parkinson's Disease. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, pages 619–622, New York, NY. ACM, 2011.

[MR74] A. Mehrabian and J. A. Russell. *An Approach to Environmental Psychology*. The MIT Press, 1974.

[MSK+18] F. Meirose, S. Schultze, S. Kuehlewind, M. Koelle, L. Abdenebaoui, and S. Boll. Towards Respectful Smart Glasses through Conversation Detection. In *Mensch und Computer 2018 - Tagungsband*, Bonn, Germany. Gesellschaft für Informatik e.V., 2018.

[MT14] M. A. Memon and J. Tanaka. Ensuring Privacy during Pervasive Logging by a Passerby. *Journal of Information Processing*, 22(2):334–343, 2014.

[Men91] R. E. Mensel. "Kodakers Lying in Wait": Amateur Photography and the Right of Privacy in New York, 1885-1915. *AM QUART*, 43(1):24, 1991.

[Mey19] H. Meyer. *A Scenario Generator for Evaluating the Social Acceptability of Emerging Technologies*. Master's thesis, University of Oldenburg, Oldenburg, Germany, 2019.

[MKB19] H. Meyer, M. Koelle, and S. Boll. A Scenario Generator for Evaluating the Social Acceptability of Emerging Technologies. *Human Computer Interaction and Emerging Technologies: Adjunct Proceedings from the IFIP Conference on Human-Computer Interaction*, 2019.

[Mic14] M. Michalko. *Thinkpak: A Brainstorming Card Deck*. Ten Speed Press, New York, 2014.

[MA16] S. Mirzamohammadi and A. Amiri Sani. Viola: Trustworthy Sensor Notifications for Enhanced Privacy on Mobile Systems. In *Proceedings of the Conference on Mobile Systems, Applications, and Services (MobiSys'16)*, pages 263–276, 2016.

[MKD+14] A. Möller, M. Kranz, S. Diewald, L. Roalter, R. Huitl, T. Stockinger, M. Koelle, and P. A. Lindemann. Experimental Evaluation of User Interfaces for Visual Indoor Navigation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 3607–3616, New York, NY. ACM, 2014.

[MKS+13] A. Möller, M. Kranz, B. Schmid, L. Roalter, and S. Diewald. Investigating Self-reporting Behavior in Long-term Studies. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*, pages 2931–2940, New York, NY. ACM, 2013.

[Mon15] T. Monahan. The Right to Hide? Anti-Surveillance Camouflage and the Aestheticization of Resistance. *COMMUN CRIT-CULT STU*, 12(2):159–178, 2015.

[MCP+04] A. Monk, J. Carroll, S. Parker, and M. Blythe. Why Are Mobile Phones Annoying? *BEHAV INFORM TECHNOL*, 23(1):33–41, 2004. URL: http://dx.doi.org/10.1080/01449290310001638496.

[MAM+10] C. S. Montero, J. Alexander, M. T. Marshall, and S. Subramanian. Would you do that?: Understanding Social Acceptance of Gestural Interfaces. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services*

(MobileCHI'10), page 275, New York, New York, USA. ACM Press, 2010.

[Mor79] D. Morris. *Gestures, their Origins and Distribution*. Stein & Day Pub, 1979.

[MC16] V. G. Motti and K. Caine. Towards a Visual Vocabulary for Privacy Concepts. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 60(1):1078–1082, 2016.

[MJ93] J. Moyes and P. W. Jordan. Icon Design and its Effect on Guessability, Learnability, and Experienced User Performance. *People and Computers*, (8):49–60, 1993.

[MGV+14] F. Mueller, M. R. Gibbs, F. Vetere, and D. Edge. Supporting the Creative Game Design Process with Exertion Cards. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 2211–2220, New York, NY. ACM, 2014.

[MKB13] S. Mueller, B. Kruck, and P. Baudisch. LaserOrigami: Laser-cutting 3D Objects. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*, page 2585, New York, NY. ACM, 2013.

[MD09] M. J. Muller and A. Druin. Participatory Design: the Third Space in HCI. In A. Sears and J. A. Jacko, editors, *Human-Computer Interaction*, pages 181–202. CRC press, 2009.

[MAF+17] K. Murata, A. A. Adams, Y. Fukuta, Y. Orito, M. Arias-Oliva, and J. Pelegrin-Borondo. From a Science Fiction to Reality: Cyborg Ethics in Japan. *COMPUT SOC*, 47(3):72–85, 2017. URL: `http://doi.acm.org/10.1145/3144592.3144600`.

[NSY+13] S. Nanayakkara, R. Shilkrot, K. P. Yeo, and P. Maes. EyeRing: A Finger-worn Input Device for Seamless Interactions with Our Surroundings. In *Proceedings of the Augmented Human International Conference (AH'13)*, pages 13–20, New York, NY, USA. ACM, 2013.

[NPF+06] W. Narzt, G. Pomberger, A. Ferscha, D. Kolb, R. Müller, J. Wieghardt, H. Hörtner, and C. Lindinger. Augmented Reality Navigation Systems. *UNIVERSAL ACCESS INF*, 4(3):177–187, 2006.

[NBA17] I. Naz, R. S. Bashir, and K. A. Alam. Measuring the Impact of Changing Technology in Mobile Phones on User Device Interaction Based on a Qualitative Survey. In *Proceedings of the IFIP Conference on e-Business, e-Services and e-Society (I3E'17)*, pages 9–14, New York, NY, USA. ACM, 2017.

[NG03] C. Neustaedter and S. Greenberg. The Design of a Context-Aware Home Media Space for Balancing Privacy and Awareness. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'03)*, volume 2864, pages 297–314, Berlin, Heidelberg. Springer Berlin Heidelberg, 2003.

[NG12] C. Neustaedter and S. Greenberg. Intimacy in Long-distance Relationships over Video Chat. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'12)*, page 753, New York, NY. ACM, 2012.

[NBB+11] D. H. Nguyen, A. Bedford, A. G. Bretana, and G. R. Hayes. Situating the Concern for Information Privacy through an Empirical Study of Responses to Video Recording. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, page 3207, New York, NY. ACM, 2011.

[NMH+09] D. H. Nguyen, G. Marcu, G. R. Hayes, K. N. Truong, J. Scott, M. Langheinrich, and C. Roduner. Encountering SenseCam: Personal Recording Technologies in Everyday Life. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'09)*, pages 165–174, New York, N.Y. ACM, 2009.

[NOP+06] C. M. Nielsen, M. Overgaard, M. B. Pedersen, J. Stage, and S. Stenild. It's worth the hassle!: the Added Value of Evaluating the Usability of Mobile Systems in the Field. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'06)*, pages 272–280, New York, New York, USA. ACM Press, 2006.

[Nie92] J. Nielsen. Finding Usability Problems Through Heuristic Evaluation. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, pages 373–380, New York, NY. ACM, 1992.

[Nie94] J. Nielsen. *Usability Engineering*. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA, 1994. URL: https://dl.acm.org/doi/book/10.5555/2821575.

[NLL14] J. B. Nikander, L. A. Liikkanen, and M. Laakso. The Preference Effect in Design Concept Evaluation. *DES STUD*, 35(5):473–499, 2014.

[NJ08] S. Nilsson and B. Johansson. Acceptance of Augmented Reality Instructions in a Real Work Setting. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'08)*, page 2025, New York, NY. ACM, 2008.

[OCM+13] G. O'Loughlin, S. J. Cullen, A. McGoldrick, S. O'Connor, R. Blain, S. O'Malley, and G. D. Warrington. Using a Wearable Camera to Increase the Accuracy of Dietary Analysis. *AM J PREV MED*, 44(3):297–301, 2013.

[ON17] M. Odamaki and S. K. Nayar. Cambits: a Reconfigurable Camera System. *COMMUN ACM*, 60(11):54–61, 2017.

[OSM+13] M. Ogata, Y. Sugiura, Y. Makino, M. Inami, and M. Imai. SenSkin: Adapting Skin As a Soft Interface. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'13)*, pages 539–544, New York, NY, USA. ACM, 2013.

[OSO+12] M. Ogata, Y. Sugiura, H. Osawa, and M. Imai. iRing: Intelligent Ring Using Infrared Reflection. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'12)*, pages 131–136, New York, NY, USA. ACM, 2012.

[OF14] U. Oh and L. Findlater. Design of and Subjective Response to On-body Input for People with Visual Impairments. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'14)*, pages 115–122, New York, NY, USA. ACM, 2014.

[OSP+17] U. Oh, L. Stearns, A. Pradhan, J. E. Froehlich, and L. Findlater. Investigating Microinteractions for People with Visual Impairments and the Potential Role of On-Body Interaction. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'17)*, pages 22–31, New York, NY, USA. ACM, 2017.

[OSF17] T. Orekondy, B. Schiele, and M. Fritz. Towards a Visual Privacy Advisor: Understanding and Predicting Privacy Risks in Images. In *IEEE International Conference on Computer Vision (ICCV'17)*, pages 3706–3715. IEEE, 2017.

[OMN14] A. Oreskovic, S. McBride, and M. Nayak. Google Glass Future Clouded as some Early Believers Lose Faith. Reuters, editor, 2014. URL: `https://www.reuters.com/article/us-google-glass-insight/google-glass-future-clouded-as-some-early-believers-lose-faith-idUSKCN0IY18E20141114` (visited on 08/15/2019).

[OD13] Organisation for Economic Co-operation and Development. *OECD Guidelines on the Protection of Privacy and Transborder Flows of Personal Data*. OECD Publishing, 2013. URL: `http://acts.oecd.org/Instruments/ShowInstrumentView.aspx?InstrumentID=114&InstrumentPID=312&Lang=en`.

[OvW82] H. J. Otway and D. von Winterfeldt. Beyond Acceptable Risk: On the Social Acceptability of Technologies. *POLICY SCI*, 14(3):247–256, 1982.

[PKR+17] J. Paay, J. Kjeldskov, D. Raptis, M. B. Skov, I. S. Penchev, and E. Ringhauge. Cross-device Interaction with Large Displays in Public: Insights from Both Users' and Observers' Perspectives. In *Proceedings of the Australasian Computer-Human Interaction Conference (OzCHI'17)*, pages 87–97, New York, NY, USA. ACM, 2017.

[Pae14] V. Paelke. Augmented Reality in the Smart Factory: Supporting Workers in an Industry 4.0. Environment. In *Proceedings of the IEEE Emerging Technology and Factory Automation (ETFA'14)*, pages 1–4. IEEE, 2014.

[PSY00] L. Palen, M. Salzman, and E. Youngs. Going Wireless: Behavior & Practice of New Mobile Phone Users. In *Proceedings of the Conference on Computer Supported Cooperative Work (CSCW'00)*, pages 201–210, New York, NY, USA. ACM Press, 2000.

[Pan16] S. Pandey. Proto Design Practice: Translating Design Thinking Practices to Organizational Settings. *ID&A Interaction Design & Architecture*, 27:129–158, 2016.

[PYK+14] P. Pappachan, R. Yus, P. Kumar Das, T. Finin, E. Mena, and A. Joshi. A Semantic Context-Aware Privacy Model for FaceBlock. In *Proceedings of the International Workshop on Society, Privacy and the Semantic Web*, 2014.

[PM18] H. Park and S. McKilligan. A Systematic Literature Review for Human-Computer Interaction and Design Thinking Process Integration. In A. Marcus and W. Wang, editors, *Design, User Experience, and Usability: Theory and Practice*. Volume 10918, pages 725–740. Springer International Publishing, Cham, 2018.

[PME11] K. Pauly-Takacs, C. J. A. Moulin, and E. J. Estlin. SenseCam as a Rehabilitation Tool in a Child with Anterograde Amnesia. *MEMORY*, 19(7):705–712, 2011.

[Pay13] C. Payne. Autographer's Automatic Photography is Seductive - But what about Privacy?, 31.07.2013. URL: `https://www.theguardian.com/technology/2013/jul/31/autographer-review-wearable-camera-documentally` (visited on 08/15/2019).

[PRJ15] J. Pearson, S. Robinson, and M. Jones. It's About Time: Smartwatches As Public Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 1257–1266, New York, NY. ACM, 2015.

[PZG17] A. J. Perez, S. Zeadally, and S. Griffith. Bystanders' Privacy. *IT PROF*, 19(3):61–65, 2017.

[PSH+11] S. Pidcock, R. Smits, U. Hengartner, and I. Goldberg. Notisense: An Urban Sensing Notification System to Improve Bystander Privacy. In *Proceedings of the International Workshop on Sensing Applications on Mobile Phones at the ACM Conference on Embedded Networked Sensor Systems*, 2011.

[PF16] D. Pohl and Fernandez de Tejada Quemada, Carlos. See What I See: Concepts to Improve the Social Acceptance of HMDs. In *Proceedings of the IEEE Virtual Reality Conference (VR'16)*, pages 267–268, 2016.

[PMH19] H. Pohl, A. Muresan, and K. Hornbæk. Charting Subtle Interaction in the HCI Literature. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, pages 1–15, New York, NY. ACM, 2019.

[PPH+11] B. Poppinga, M. Pielot, W. Heuten, and S. Boll. Evaluating Mobile Accessible Applications is a Challenge: Can the Virtual Observer be a Proper Solution? In *Proceedings of the Mobile Accessibility Workshop in conjunction with INTERACT'11.* 2011.

[PFR+18] M. Porcheron, J. E. Fischer, S. Reeves, and S. Sharples. Voice Interfaces in Everyday Life. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, 640:1–640:12, New York, NY. ACM, 2018.

[PLE+15] R. S. Portnoff, L. N. Lee, S. Egelman, P. Mishra, D. Leung, and D. Wagner. Somebody's Watching Me?: Assessing the Effectiveness of Webcam Indicator Lights. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 1649–1658, New York, NY. ACM, 2015.

[PIF+04] Z. Pousman, G. Iachello, R. Fithian, J. Moghazy, and J. Stasko. Design Iterations for a Location-aware Event Planner. *PERS UBIQUIT COMPUT*, 8(2):117–125, 2004.

[PRS15] J. Preece, Y. Rogers, and H. Sharp. *Interaction design: Beyond human-computer interaction.* Wiley, Chichester, fourth edition edition, 2015.

[Pre14] S. Preibusch. Eye-tracking. Privacy Interfaces for the next Ubiquitous Modality, 2014. URL: `https://www.w3.org/2014/privacyws/pp/Preibusch.pdf` (visited on 08/15/2019).

[PSC+17] B. A. Price, A. Stuart, G. Calikli, C. Mccormick, V. Mehta, L. Hutton, A. K. Bandara, M. Levine, and B. Nuseibeh. Logging You, Logging Me: A Replicable Study of Privacy and Sharing Behaviour in Groups of Visual Lifeloggers. *PROC ACM IMWUT*, 1(2):22:1–22:18, 2017. URL: `http://doi.acm.org/10.1145/3090087`.

[PLH+14] K. Probst, D. Lindlbauer, M. Haller, B. Schwartz, and A. Schrempf. A Chair As Ubiquitous Input Device: Exploring Semaphoric Chair Gestures for Focused and Peripheral Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 4097–4106, New York, NY. ACM, 2014.

[Pro16] H. Profita. Designing Wearable Computing Technology for Acceptability and Accessibility. *ACM SIGACCESS Accessibility and Computing*, (114):44–48, 2016.

[PAF+16] H. Profita, R. Albaghli, L. Findlater, P. Jaeger, and S. K. Kane. The AT Effect: How Disability Affects the Perceived Social Acceptability of Head-Mounted Display Use. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, pages 4884–4895, New York, NY. ACM, 2016.

[PCG+13] H. Profita, J. Clawson, S. Gilliland, C. Zeagler, T. Starner, J. Budd, and E. Y.-L. Do. Don't Mind me Touching my Wrist: a Case Study of Interacting with On-body Technology. In *Proceedings of the International Symposium on Wearable Computers (ISWC'13)*, pages 89–96, 2013.

[PFC15] H. Profita, N. Farrow, and N. Correll. Flutter: An Exploration of an Assistive Garment Using Distributed Sensing, Computation and Actuation. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction (TEI'15)*, pages 359–362, New York, NY, USA. ACM, 2015.

[PSM+16] H. Profita, A. Stangl, L. Matuszewska, S. Sky, and S. K. Kane. Nothing to Hide: Aesthetic Customization of Hearing Aids and Cochlear Implants in an Online Community. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'16)*, pages 219–227, New York, New York, USA. ACM Press, 2016.

[PSM+18] H. Profita, A. Stangl, L. Matuszewska, S. Sky, R. Kushalnagar, and S. K. Kane. "Wear It Loud": How and Why Hearing Aid and Cochlear Implant Users Customize Their Devices. *ACM TRANS ACCESS COMPUT*, 11(3):13:1–13:32, 2018. URL: `http://doi.acm.org/10.1145/3214382`.

[QT10] J. M. Quinn and T. Q. Tran. Attractive phones don't have to work better: Independent Effects of Attractiveness, Effectiveness, and Efficiency on Perceived Usability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'10)*, page 353, New York, NY. ACM, 2010.

[RBN+13] K. Radke, C. Boyd, J. G. Nieto, and L. Buys. Who decides?: Security and Privacy in the Wild. In *Proceedings of the Australasian Computer-Human Interaction Conference (OzCHI'13)*, pages 27–36, New York, New York, USA. ACM Press, 2013.

[RBK+17] D. Raptis, A. Bruun, J. Kjeldskov, and M. B. Skov. Converging Coolness and Investigating its Relation to User Experience. *BEHAV INFORM TECHNOL*, 36(4):333–350, 2017.

[RBI15] P. A. Rauschnabel, A. Brem, and B. S. Ivens. Who will Buy Smart Glasses? Empirical Results of two Pre-market-entry Studies on the Role of Personality in Individual Awareness and Intended Adoption of Google Glass Wearables. *COMPUT HUM BEHAV*, 49:635–647, 2015.

[RHH+16] P. A. Rauschnabel, D. W. Hein, J. He, Y. K. Ro, S. Rawashdeh, and B. Krulikowski. Fashion or Technology? A Fashnology Perspective on the Perception and Adoption of Augmented Reality Smart Glasses. *i-com*, 15(2):179–194, 2016.

[RR16] P. A. Rauschnabel and Y. K. Ro. Augmented Reality Smart Glasses: An Investigation of Technology Acceptance Drivers. *INT J TECH MARKET*, 11(2):123, 2016.

[RA15] S. S. Rautaray and A. Agrawal. Vision Based Hand Gesture Recognition for Human Computer Interaction: a Survey. *ARTIF INTELL REV*, 43(1):1–54, 2015.

[RCS+14] N. Raval, L. Cox, A. Srivastava, A. Machanavajjhala, and K. Lebeck. MarkIt: Privacy Markers for Protecting Visual Secrets. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'14)*, pages 1289–1295, New York, NY, USA. ACM, 2014.

[RBO+05] S. Reeves, S. Benford, C. O'Malley, and M. Fraser. Designing the Spectator Experience. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'05)*, pages 741–750, New York, NY. ACM, 2005.

[Reg16] G. D. P. Regulation. Regulation (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the Protection of Natural Persons with regard to the Processing of Personal Data and on the Free Movement of such Data, and Repealing Directive 95/46. *Official Journal of the European Union (OJ)*, 59(1-88):294, 2016.

[RdSC08] T. Reis, M. de Sá, and L. Carriço. Multimodal Interaction: Real Context Studies on Mobile Digital Artefacts. In *International Workshop on Haptic and Audio Interaction Design*, pages 60–69, 2008.

[Rek01] J. Rekimoto. GestureWrist and GesturePad: Unobtrusive Wearable Interaction Devices. In *Proceedings of the International Symposium on Wearable Computers (ISWC'01)*, pages 21–27. IEEE Computer Society, 2001.

[RB09] J. Rico and S. Brewster. Gestures all Around Us: User Differences in Social Acceptability Perceptions of Gesture Based Interfaces. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'09)*, page 1, New York, New York, USA. ACM Press, 2009.

[RB10a] J. Rico and S. Brewster. Gesture and Voice Prototyping for Early Evaluations of Social Acceptability in Multimodal Interfaces. In *Proceedings of the International Conference on Multimodal Interfaces and the Workshop on Machine Learning for Multimodal Interaction (ICMI-MLMI'10)*, 16:1–16:9, New York, NY, USA. ACM, 2010.

[RB10b] J. Rico and S. Brewster. Usable Gestures for Mobile Interfaces: Evaluating Social Acceptability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'10)*, page 887, New York, NY. ACM, 2010.

[Rie18] C. Riedmann-Streitz. Redefining the Customer Centricity Approach in the Digital Age. In A. Marcus and W. Wang, editors, *Design, User Experience, and Usability: Theory and Practice.* Volume 10918, pages 203–222. Springer International Publishing, Cham, 2018.

[RFI+13] M. J. Rissanen, O. N. N. Fernando, H. Iroshan, S. Vu, N. Pang, and S. Foo. Ubiquitous Shortcuts: Mnemonics by Just Taking Photos. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'13)*, pages 1641–1646, New York, NY. ACM, 2013.

[Rog10] E. M. Rogers. *Diffusion of Innovations (4th Edition)*. Free Press, Simon and Schuster Inc, New York, NY, USA, 2010.

[RCT+07] Y. Rogers, K. Connelly, L. Tedesco, W. Hazlewood, A. Kurtz, R. E. Hall, J. Hursey, and T. Toscos. Why It's Worth the Hassle: The Value of In-Situ Studies When Designing Ubicomp. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'07)*, volume 4717, pages 336–353, Berlin, Heidelberg. Springer Berlin Heidelberg, 2007.

[RHK+07] S. Ronkainen, J. Häkkilä, S. Kaleva, A. Colley, and J. Linjama. Tap Input as an Embedded Interaction Method for Mobile Devices. In *Proceedings of the International Conference on Tangible and*

Embedded Interaction (TEI'07), page 263, New York, New York, USA. ACM Press, 2007.

[Ros17] E. Rose. Datenbrillen, Drohnen, Dashcams ... Smart Cams im öffentlichen Raum allein durch Rechtsprechung nicht beherrschbar. *Datenschutz und Datensicherheit - DuD*, 41(3):137–141, 2017.

[RRC+17] S. Ruffieux, N. Ruffieux, R. Caldara, and D. Lalanne. iKnowU – Exploring the Potential of Multimodal AR Smart Glasses for the Decoding and Rehabilitation of Face Processing in Clinical Populations. In R. Bernhaupt, G. Dalvi, A. Joshi, D. K. Balkrishan, J. O'Neill, and M. Winckler, editors, *Proceedings of the IFIP Conference on Human-Computer Interaction*. Volume 10515, pages 423–432. Springer, 2017.

[RKK97] D. C. Ruspini, K. Kolarov, and O. Khatib. The Haptic Display of Complex Graphical Environments. In *Proceedings of the Annual Conference on Computer Graphics and Interactive Techniques (SIGGRAPH'97)*, pages 345–352, New York, New York, USA. ACM Press, 1997.

[SZ88] W. Samuelson and R. Zeckhauser. Status Quo Bias in Decision Making. *J RISK UNCERTAINTY*, 1(1):7–59, 1988.

[San01] E. B. N. Sanders. Virtuosos of the Experience Domain. In *Proceedings of the IDSA National Education Conference*, 2001.

[STO18] N. Savela, T. Turja, and A. Oksanen. Social Acceptance of Robots in Different Occupational Fields: A Systematic Literature Review. *INT J SOC ROBOT*, 10(4):493–502, 2018.

[SBD+15] F. Schaub, R. Balebako, A. L. Durity, and L. F. Cranor. A Design Space for Effective Privacy Notices. In *Proceedings of the Symposium On Usable Privacy and Security (SOUPS'15)*, pages 1–17. USENIX Association, 2015.

[SMM+09] J. Schiff, M. Meingast, D. K. Mulligan, S. Sastry, and K. Goldberg. Respectful Cameras: Detecting Visual Markers in Real-Time to Address Privacy Concerns. In A. Senior, editor, *Protecting Privacy in Video Surveillance*, pages 65–89. Springer London, London, 2009.

[SWO18] M. L. Schilling, R. Wakkary, and W. Odom. Focus Framework: Tracking Prototypes' Back-Talk. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction (TEI'18)*, pages 684–693, New York, NY, USA. ACM, 2018.

[SKL11] R. Schlegel, A. Kapadia, and A. J. Lee. Eyeing your Exposure: Quantifying and Controlling Information Sharing for Improved Privacy. In *Proceedings of the Symposium on Usable Privacy and Security*, page 1, New York, NY, USA. ACM, 2011.

[SBG99] A. Schmidt, M. Beigl, and H.-W. Gellersen. There is More to Context than Location. *COMPUT GRAPH*, 23(6):893–901, 1999.

[SEU+18] H. Schneider, M. Eiband, D. Ullrich, and A. Butz. Empowerment in HCI - A Survey and Framework. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, pages 1–14, New York, NY. ACM, 2018.

[SLZ18] E.-M. Schomakers, C. Lidynia, and M. Ziefle. Hidden within a Group of People-Mental Models of Privacy Protection. In *Proceedings of the International Conference on Internet of Things, Big Data and Security*, pages 85–94, Setúbal, Portugal. SCITEPRESS, 2018.

[Sch+00] T. A. Schwandt et al. Constructivist, Interpretivist Approaches to Human Inquiry. In N. K. Denzin and Y. S. Lincoln, editors, *Handbook of Qualitative Research*. Volume 1, pages 118–137. Sage Publ, Thousand Oaks, 2000.

[Sch16] T. Schwenke. *Private Nutzung von Smartglasses im öffentlichen Raum*. Dissertation, Carl von Ossietzky Universität Oldenburg and OLWIR Oldenburger Verlag für Wirtschaft, Informatik und Recht, 2016.

[SRR+18] V. Schwind, J. Reinhardt, R. Rzayev, N. Henze, and K. Wolf. Virtual Reality on the Go?: A Study on Social Acceptance of VR Glasses. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'18)*, pages 111–118, New York, NY, USA. ACM, 2018.

[SSW19] C. Seifert, S. Scherzinger, and L. Wiese. Towards Generating Consumer Labels for Machine Learning Models. In *Proceedings of the IEEE International Conference on Cognitive Machine Intelligence*, pages 173–179, 2019.

[SFA+07] A. J. Sellen, A. Fogg, M. Aitken, S. Hodges, C. Rother, and K. Wood. Do Life-logging Technologies Support Memory for the Past? In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'07)*, page 81, New York, NY, USA. ACM, 2007.

[Sel03] N. Selwyn. Apart from Technology: Understanding People's Non-use of Information and Communication Technologies in Everyday Life. *TECHNOL SOC*, 25(1):99–116, 2003.

[SEI14] M. Serrano, B. M. Ens, and P. P. Irani. Exploring the Use of Hand-to-Face Input for Interacting with Head-worn Displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 3181–3190, New York, NY. ACM, 2014.

[Sha09] B. Shackel. Usability – Context, Framework, Definition, Design and Evaluation. *INTERACT COMPUT*, 21(5-6):339–346, 2009. URL: http://dx.doi.org/10.1016/j.intcom.2009.04.007.

[SW11] K. Shinohara and J. O. Wobbrock. In the Shadow of Misperception: Assistive Technology Use and Social Interactions. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, pages 705–714, New York, NY. ACM, 2011.

[SR96] B. Shneiderman and A. Rose. Social Impact Statements: Engaging Public Participation in Information Technology Design. In *Proceedings of the Symposium on Computers and the Quality of Life (CQL'96)*, pages 90–96, New York, NY, USA. ACM Press, 1996.

[SZH17] J. Shu, R. Zheng, and P. Hui. Your Privacy Is in Your Hand: Interactive Visual Privacy Control with Tags and Gestures. In *International Conference on Communication Systems and Networks*, pages 24–43, Cham. Springer International Publishing, 2017.

[SZH18] J. Shu, R. Zheng, and P. Hui. Cardea: Context-aware Visual Privacy Protection for Photo Taking and Sharing. In *Proceedings of the ACM Multimedia Systems Conference on Multimedia Systems (MMSys'18)*, pages 304–315, New York, New York, USA. ACM, 2018.

[SNS+16] S. Singhal, C. Neustaedter, T. Schiphorst, A. Tang, A. Patra, and R. Pan. You are Being Watched: Bystanders' Perspective on the Use of Camera Devices in Public Spaces. In *Proceedings of the SIGCHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI'16 EA)*, pages 3197–3203, New York, New York, USA. ACM Press, 2016.

[Smi98] G. F. Smith. Idea-generation Techniques: A Formulary of Active Ingredients. *J CREATIVE BEHAV*, 32(2):107–134, 1998.

[Soa16] M. M. Soares. *Ergonomics in Design: Methods and Techniques*. CRC press, Milton, 2016. URL: http://gbv.eblib.com/patron/FullRecord.aspx?p=4694430.

[SPS+15] J. Song, F. Pece, G. Sörös, M. Koelle, and O. Hilliges. Joint Estimation of 3D Hand Position and Gestures from Monocular Video for Mobile Interaction. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 3657–3660, New York, NY. ACM, 2015.

[SWP98] T. Starner, J. Weaver, and A. Pentland. Real-time American sign language recognition using desk and wearable computer based video. *IEEE T PATTERN ANAL*, 20(12):1371–1375, 1998.

[SMR+97] T. Starner, S. Mann, B. Rhodes, J. Levine, J. Healey, D. Kirsch, R. W. Picard, and A. Pentland. Augmented Reality through Wearable Computing. *PRESENCE-TELEOP VIRT*, 6(4):386–398, 1997.

[SFF18] L. Stearns, L. Findlater, and J. E. Froehlich. Design of an Augmented Reality Magnification Aid for Low Vision Users. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'18)*, pages 28–39, New York, NY, USA. ACM, 2018.

[SB15a] J. Steil and A. Bulling. Discovery of Everyday Human Activities from Long-term Visual Behaviour using Topic Models. In *Proceedings of the ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp'15)*, pages 75–85, New York, NY, USA. ACM, 2015.

[SHH+19] J. Steil, I. Hagestedt, M. X. Huang, and A. Bulling. Privacy-aware Eye Tracking using Differential Privacy. In *Proceedings of the ACM Symposium on Eye Tracking Research & Applications (ETRA'19)*, pages 1–9, New York, NY, USA. ACM Press, 2019.

[SKH+19] J. Steil, M. Koelle, W. Heuten, S. Boll, and A. Bulling. PrivacEye: Privacy-preserving Head-mounted Eye Tracking Using Egocentric Scene Image and Eye Movement Features. In *Proceedings of the ACM Symposium on Eye Tracking Research & Applications*, 26:1–26:10, New York, NY, USA. ACM, 2019.

[SMS+18] J. Steil, P. Müller, Y. Sugano, and A. Bulling. Forecasting User Attention during Everyday Mobile Interactions using Device-integrated and Wearable Sensors. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'18)*, pages 1–13, New York, NY, USA. ACM, 2018.

[SB15b] Y. Sugano and A. Bulling. Self-Calibrating Head-Mounted Eye Trackers Using Egocentric Visual Saliency. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'15)*, pages 363–372, New York, New York, USA. ACM Press, 2015.

[SSH+16] H. Suh, N. Shahriaree, E. B. Hekler, and J. A. Kientz. Developing and Validating the User Burden Scale: A Tool for Assessing User Burden in Computing Systems. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'16)*, pages 3988–3999, New York, NY. ACM, 2016.

[STW14] S. S. Sundar, D. J. Tamul, and M. Wu. Capturing "cool": Measures for Assessing Coolness of Technological Products. *INT J HUM-COMPUT ST*, 72(2):169–180, 2014.

[Sut68] I. E. Sutherland. A Head-mounted Three Dimensional Display. In *Proceedings of the AFIPS Fall Joint Computer Conference*, page 757, New York, New York, USA. ACM Press, AFIPS, and Thomson Book Company, 1968.

[Swa19] F. Swain. These Colorful Stickers are Helping Blind People find their Way Around. MIT Technology Review, editor, 2019. URL: https://www.technologyreview.com/s/613632/these-colorful-stickers-are-helping-blind-people-find-their-way-around/ (visited on 08/15/2019).

[SLJ+14] C. Szegedy, W. Liu, Y. Jia, P. Sermanet, S. Reed, D. Anguelov, D. Erhan, V. Vanhoucke, and A. Rabinovich. Going Deeper with Convolutions, 2014. URL: http://arxiv.org/pdf/1409.4842v1.

[Tae17] J. Taeger. *Chancen und Risiken von Smart Cams im öffentlichen Raum*, volume v.7. Nomos Verlagsgesellschaft, Baden-Baden, 1st ed. Edition, 2017. URL: https://ebookcentral.proquest.com/lib/gbv/detail.action?docID=5519482.

[TBS18] A. Taniberg, L. Botin, and K. Stec. Context of Use Affects the Social Acceptability of Gesture Interaction. In *Proceedings of the Nordic Conference on Human-Computer Interaction (NordiCHI'18)*, pages 731–735, New York, NY, USA. ACM, 2018.

[Tat90] S. Tatsuno. *Created in Japan: From Imitators to world-class Innovators*. Ballinger Pub Co, 1990.

[TKC+14] R. Templeman, M. Korayem, D. J. Crandall, and A. Kapadia. PlaceAvoider: Steering First-Person Cameras away from Sensitive Spaces. In *Proceedings of the Network and Distributed System Security Symposium (NDSS'14)*, pages 23–26, 2014.

[Tho07] E. R. Thompson. Development and Validation of an Internationally Reliable Short-Form of the Positive and Negative Affect Schedule (PANAS). *J CROSS CULT PSYCHOL*, 38(2):227–242, 2007.

[Tho99] S. C. Thompson. Illusions of Control How We Overestimate Our Personal Influence. *CURR DIR PSYCHOL SCI*, 8(6):187–190, 1999.

[TTZ17] S. Thunberg, S. Thellman, and T. Ziemke. Don't Judge a Book by its Cover: A Study of the Social Acceptance of NAO vs. Pepper. In *Proceedings of the International Conference on Human Agent Interaction (HAI'17)*, pages 443–446, New York, New York, USA. ACM Press, 2017.

[TMT+03] A. Toney, B. Mulley, B. H. Thomas, and W. Piekarski. Social Weight: Designing to Minimise the Social Consequences arising from Technology Use by the Mobile Professional. *PERS UBIQUIT COMPUT*, 7(5):309–320, 2003.

[TKI00] N. Tractinsky, A. S. Katz, and D. Ikar. What is Beautiful is Usable. *Interacting with Computers*, 13(2):127–145, 2000.

[TvdM98] J. Triesch and C. von der Malsburg. Robotic Gesture Recognition by Cue Combination. In W. Brauer, J. Dassow, and R. Kruse, editors, *Informatik '98*. Volume 42, pages 223–232. Springer Berlin Heidelberg, Berlin, Heidelberg, 1998.

[TPS+05] K. N. Truong, S. N. Patel, J. W. Summet, and G. D. Abowd. Preventing Camera Recording by Designing a Capture-Resistant Environment. In *Proceedings of the International Conference on Ubiquitous Computing (UbiComp'05)*, pages 73–86, Berlin, Heidelberg. Springer Berlin Heidelberg, 2005.

[TH15] A. N. Tuch and K. Hornbæk. Does Herzberg's Notion of Hygienes and Motivators Apply to User Experience? *ACM T COMPUT-HUM INT*, 22(4):1–24, 2015.

[TRH+12] A. N. Tuch, S. P. Roth, K. Hornbæk, K. Opwis, and J. A. Bargas-Avila. Is beautiful really usable? Toward Understanding the Relation between Usability, Aesthetics, and Affect in HCI. *COMPUT HUM BEHAV*, 28(5):1596–1607, 2012.

[THW+15] Y.-C. Tung, C.-Y. Hsu, H.-Y. Wang, S. Chyou, J.-W. Lin, P.-J. Wu, A. Valstar, and M. Y. Chen. User-Defined Game Input for Smart Glasses in Public Space. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 3327–3336, New York, NY. ACM, 2015.

[VM07] K. Vaajakallio and T. Mattelmäki. Collaborative Design Exploration: Envisioning Future Practices with Make Tools. In *Proceedings of the Conference on Designing Pleasurable Products and Interfaces (DPPO'07)*, page 223, New York, NY, USA. ACM, 2007.

[van13] K. M. van Mensvoort. *Pyramid of Technology: How Technology becomes Nature in Seven Steps*. Technische Universiteit Eindhoven, Eindhoven, the Netherlands, 2013. URL: `https://pure.tue.nl/ws/files/3805415/760124.pdf`.

[Van07] G. R. Vandenbos. *APA Dictionary of Psychology*. American Psychological Assoc, Washington, 1. ed. Edition, 2007.

[VM00] V. Venkatesh and M. G. Morris. Why Don't Men Ever Stop to Ask for Directions? Gender, Social Influence, and Their Role in Technology Acceptance and Usage Behavior. *MIS Q*, 24(1):115–139, 2000. URL: `http://dx.doi.org/10.2307/3250981`.

[VBS15] S. Verma, H. Bansal, and K. Sorathia. A Study for Investigating Suitable Gesture Based Selection for Gestural User Interfaces. In *Proceedings of the International Conference on HCI (IndiaHCI'15)*, pages 47–55, New York, NY, USA. ACM, 2015.

[VKK+11] E. Vildjiounaite, J. Kantorovitch, V. Kyllönen, I. Niskanen, M. Hillukkala, K. Virtanen, O. Vuorinen, S.-M. Mäkelä, T. Keränen, J. Peltola, J. Mäntyjärvi, and A. Tokmakoff. Designing Socially Acceptable Multimodal Interaction in Cooking Assistants. In *Proceedings of the International Conference on Intelligent User Interfaces (IUI'11)*, pages 415–418, New York, NY, USA. ACM, 2011.

[VMS+19] A. Voit, S. Mayer, V. Schwind, and N. Henze. Online, VR, AR, Lab, and In-Situ: Comparison of Research Methods to Evaluate Smart Artifacts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, pages 1–12, New York, NY. ACM, 2019.

[Wal98] J. R. Walkowitz. Going Public: Shopping, Street Harassment, and Streetwalking in Late Victorian London. *Representations*, (62):1–30, 1998.

[WWB+14] S. Walter, C. Wendt, J. Böhnke, S. Crawcour, J.-W. Tan, A. Chan, K. Limbrecht, S. Gruss, and H. C. Traue. Similarities and Differences of Emotions in Human-machine and Human-human Interactions: What Kind of Emotions are relevant for Future Companion Systems? *ERGONOMICS*, 57(3):374–386, 2014.

[Wan17] E. Wanckel. *Foto- und Bildrecht*. C.H. Beck, München, 5. auflage edition, 2017.

[WCC+15] C.-Y. Wang, W.-C. Chu, P.-T. Chiu, M.-C. Hsiu, Y.-H. Chiang, and M. Y. Chen. PalmType: Using Palms As Keyboards for Smart Glasses. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (MobileHCI'15)*, pages 153–160, New York, NY, USA. ACM, 2015.

[WSL+16] S. Wang, J. Song, J. Lien, I. Poupyrev, and O. Hilliges. Interacting with Soli: Exploring Fine-Grained Dynamic Gesture Recognition in the Radio-Frequency Spectrum. In *Proceedings of the ACM Symposium on User Interface Software and Technology (UIST'16)*, pages 851–860, New York, New York, USA. ACM Press, 2016.

[WWV+17] P. Washington, D. Wall, C. Voss, A. Kline, N. Haber, J. Daniels, A. Fazel, T. De, C. Feinstein, and T. Winograd. Superpowerglass: A Wearable Aid for the At-home Therapy of Children with Autism. *PROC ACM IMWUT*, 1(3):1–22, 2017.

[Web19] A. Weber. *Can Anthropomorphism Increase Social Acceptability? – Prototype and Evaluation of a Pan-Tilt Wearable Camera*. Bachelor's thesis, University of Oldenburg, Oldenburg, Germany, 2019.

[WLB$^+$15] M. Weigel, T. Lu, G. Bailly, A. Oulasvirta, C. Majidi, and J. Steimle. iSkin: Flexible, Stretchable and Visually Customizable On-Body Touch Sensors for Mobile Computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'15)*, pages 2991–3000, New York, NY. ACM, 2015.

[WMS14] M. Weigel, V. Mehta, and J. Steimle. More Than Touch: Understanding How People Use Skin As an Input Surface for Mobile Computing. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'14)*, pages 179–188, New York, NY. ACM, 2014.

[Wes03] A. F. Westin. Social and Political Dimensions of Privacy. *J SOC ISSUES*, 59(2):431–453, 2003.

[WRB17] R. Wetzel, T. Rodden, and S. Benford. Developing Ideation Cards for Mixed Reality Game Design. *Transactions of the Digital Games Research Association*, 3(2), 2017.

[WZ12] W. Wilkowska and M. Ziefle. Privacy and Data Security in E-health: Requirements from the User's Perspective. *HEALTH INFORM J*, 18(3):191–201, 2012.

[Wil12] J. R. Williamson. *User Experience, Performance, and Social Acceptability: Usable Multimodal Mobile Interaction*. Ph.D. Dissertation, University of Glasgow, 2012.

[WBV13] J. R. Williamson, S. Brewster, and R. Vennelakanti. Mo! Games: Evaluating Mobile Gestures In the Wild. In *Proceedings of the International Conference on Multimodal Interfaces (ICMI'13)*, pages 173–180, 2013.

[WCB11] J. R. Williamson, A. Crossan, and S. Brewster. Multimodal Mobile Interactions: Usability Studies in Real World Settings. In *Proceedings of the International Conference on Multimodal Interfaces (ICMI'11)*, pages 361–368, New York, NY, USA. ACM, 2011.

[WMO19] J. R. Williamson, M. McGill, and K. Outram. PlaneVR: Social Acceptability of Virtual Reality for Aeroplane Passengers. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'19)*, pages 1–14, New York, NY. ACM, 2019.

[WW17] J. R. Williamson and J. Williamson. Understanding Public Evaluation: Quantifying Experimenter Intervention. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'17)*, pages 3414–3425, New York, NY. ACM, 2017.

[Wil11] J. R. Williamson. Send Me Bubbles: Multimodal Performance and Social Acceptability. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'11)*, pages 899–904, New York, NY. ACM, 2011.

[WAR+05] J. O. Wobbrock, H. H. Aung, B. Rothrock, and B. A. Myers. Maximizing the Guessability of Symbolic Input. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'05)*, pages 1869–1872, New York, NY. ACM, 2005.

[WK16] J. O. Wobbrock and J. A. Kientz. Research Contribution in Human-Computer Interaction. *Interactions*, 23(3):38–44, 2016.

[WAS+15] K. Wolf, Y. Abdelrahman, D. Schmid, T. Dingier, and A. Schmidt. Effects of Camera Position and Media Type on Lifelogging Images. In *Proceedings of the International Conference on Mobile and Ubiquitous Multimedia (MUM'15)*, pages 234–244, New York, NY, USA. ACM, 2015.

[WSB+14] K. Wolf, A. Schmidt, A. Bexheti, and M. Langheinrich. Lifelogging: You're Wearing a Camera? *IEEE PERVAS COMPUT*, 13(3):8–12, 2014.

[WBM06] P. Wright, M. Blythe, and J. McCarthy. User Experience and the Idea of Design in HCI. In D. Hutchison, T. Kanade, J. Kittler, J. M. Kleinberg, F. Mattern, J. C. Mitchell, M. Naor, O. Nierstrasz, C. Pandu Rangan, B. Steffen, M. Sudan, D. Terzopoulos, D. Tygar, M. Y. Vardi, G. Weikum, S. W. Gilroy, and M. D. Harrison, editors, *Interactive Systems. Design, Specification, and Verification*. Volume 3941, pages 1–14. Springer Berlin Heidelberg, Berlin, Heidelberg, 2006.

[YGE13] T. Yamada, S. Gohshi, and I. Echizen. Privacy Visor: Method for Preventing Face Image Detection by Using Differences in Human and Device Sensitivity. In *Communications and Multimedia Security*, pages 152–161, Berlin, Heidelberg. Springer Berlin Heidelberg, 2013.

[YTT11] T. Yamamoto, T. Terada, and M. Tsukamoto. Designing Gestures for Hands and Feet in Daily Life. In *Proceedings of the Interantional Conference on Advances in Mobile Computing and Multimedia (MoMM'11)*, pages 285–288, New York, NY, USA. ACM, 2011.

[YYZ+16] H. Yang, J. Yu, H. Zo, and M. Choi. User Acceptance of Wearable Devices: An extended Perspective of Perceived Value. *TELEMAT INFORM*, 33(2):256–269, 2016.

[YXH+17] Y. Yao, H. Xia, Y. Huang, and Y. Wang. Privacy Mechanisms for Drones. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'17)*, pages 6777–6788, New York, NY. ACM, 2017.

[YHN+15] S. H. Yoon, K. Huo, V. P. Nguyen, and K. Ramani. TIMMi: Finger-worn Textile Input Device with Multimodal Sensing in Mobile Interaction. In *Proceedings of the International Conference on Tangible, Embedded, and Embodied Interaction (TEI'15)*, pages 269–272, New York, NY, USA. ACM, 2015.

[YZK+17] J. Yu, B. Zhang, Z. Kuang, D. Lin, and J. Fan. iPrivacy: Image Privacy Protection by Identifying Sensitive Objects via Deep Multi-Task Learning. *IEEE T INF FOREN SEC*, 12(5):1005–1016, 2017.

[YBA11] K. A. Yuksel, S. Buyukbas, and S. H. Adali. Designing Mobile Phones Using Silent Speech Input and Auditory Feedback. In *Proceedings of the ACM International Conference on Human-Computer Interaction with Mobile Devices and Services (Mobile-HCI'11)*, pages 711–713, New York, NY, USA. ACM, 2011.

[ZSA15] Y. Zhao, S. Szpiro, and S. Azenkot. Foresee: A Customizable Head-mounted Vision Enhancement System for People with Low Vision. In *Proceedings of the International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS'15)*, pages 239–249, New York, NY, USA. ACM, 2015.

[ZWR+18] Y. Zhao, S. Wu, L. Reynolds, and S. Azenkot. A Face Recognition Application for People with Visual Impairments. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'18)*, pages 1–14, New York, NY. ACM, 2018.

[ZR10] M. Ziefle and C. Rocker. Acceptance of Pervasive Healthcare Systems: A Comparison of Different Implementation Concepts. In *Proceedings of the International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth'10)*. IEEE, 2010.

[ZFE07] J. Zimmerman, J. Forlizzi, and S. Evenson. Research through Design as a Method for Interaction Design Research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI'07)*, page 493, New York, NY, USA. ACM, 2007.