HHS Public Access

Author manuscript

Proc ACM Interact Mob Wearable Ubiquitous Technol. Author manuscript; available in PMC 2020 April 21.

Published in final edited form as:

Proc ACM Interact Mob Wearable Ubiquitous Technol. 2018 September ; 2(3): . doi:10.1145/3264900.

I Can't Be Myself: Effects of Wearable Cameras on the Capture of Authentic Behavior in the Wild

RAWAN ALHARBI, **TAMMY STUMP**, **NILOFAR VAFAIE**, **ANGELA PFAMMATTER**, **BONNIE SPRING**, **NABIL ALSHURAFA**

Northwestern University, USA

Abstract

Wearable sensors can provide reliable, automated measures of health behaviors in free-living populations. However, validation of these measures is impossible without observable confirmation of behaviors. Participants have expressed discomfort during the use of ego-centric wearable cameras with first-person view. We argue that mounting the camera on different body locations with a different lens orientation, gives a device recording affordance that has the effect of reducing surveillance and social discomfort compared to ego-centric cameras. We call these types of cameras "activity-oriented" because they are designed to capture a particular activity, rather than the field of view of the wearer. We conducted an experiment of three camera designs with 24 participants, collecting qualitative data on participants' experience while wearing these devices in the wild. We provide a model explaining factors that lead to an increase in social presence and social stigma, which, therefore, create social and surveillance discomfort for the wearer. Wearers' attempts to reduce this discomfort by modifying their behavior or abandoning the device threatens the validity of observations of authentic behaviors. We discuss design implications and provide recommendations to help reduce social presence and stigma in order to improve the validity of observations with cameras in the wild.

Additional Key Words and Phrases:

activity-oriented camera; wearables; groundtruth; free-living populations; stigma; privacy; social presence

1 INTRODUCTION

The new opportunities provided by wearable sensors and advances in the field of computer science have enabled health researchers to redefine standards for health behavior measurement [73]. Traditional self-report methods suffer from recall bias [39] and burden on participants [10], whereas wearables can facilitate the acquisition of consistent and objective, quantifiable measures of behavior. Sensor data obtained from wearables have been used to build effective machine learning (ML) models to characterize human behavior [46, 63, 71]. For example, an ML model based on wearable sensor data can reveal fine-grained

Authors' addresses: Rawan Alharbi, Northwestern University, 680 N Lake Shore Dr, Chicago, IL, 60611, USA, rawan.alharbi@northwestern.edu.

eating behavior patterns, such as how (e.g., number and speed of feeding gestures per meal), when (time of day), and where (e.g., the social context; whether the person is alone or not) eating was performed. Such fine-grained information on behavioral patterns can lead to new insights into the design of personalized behavior change interventions.

Wearables and ML models are often first designed and evaluated in the lab before being used in a more realistic, natural setting ("the wild"). However, most ML models built from training data collected in the lab fail to recognize the expected behaviors when tested in the wild, where the accuracy of the model declines [34, 80]. This failure is due to the large intra-class variability in behavior (e.g., a person may feed in different ways depending on the utensil used) and the inter-class similarity of different behaviors (e.g., from a sensing perspective, feeding gestures appear similar to other hand gestures such as smoking or scratching one's nose). The realization that human behaviors found uniquely in complex natural settings cannot always be readily foreseen and replicated in a controlled environment has led to a paradigm shift in the field. ML models of human behavior are now increasingly being built using data gathered in the wild instead of in the lab [1, 15].

When supervised ML algorithms are used to build ML models, the quality of the model depends directly on the quality of the data collected. In the absence of more objective measures, researchers have relied on self-report as a mechanism to obtain ground truth data [15, 17], a method hindered by participant recall burden and reporting bias. However, the optimization and miniaturization of wearable cameras has provided a solution to this problem by allowing time-stamp precision and visual confirmation of ground truth behavior [18, 71]. Technology has improved the consistency that can be attained when building and optimizing ML models based on data collected in the lab and in the wild because researchers can use the same objective measure for obtaining ground truth, i.e., the camera [33]. However, there are challenges specific to collecting wearable camera data in the wild.

Researchers have used wearable cameras in the wild as a tool for observations [47, 78] and reported that participants felt uncomfortable wearing the camera in some situations, which reduced the camera wear time, thereby hindering data capture. The effects of wearable cameras on both wearers [27, 56] and bystanders [52] have been the focus of several studies, providing insight on the situations where people find it uncomfortable to wear the camera. However, findings varied between these studies; for instance, Hoyle et al. [27] reported more concern about perceived bystander reaction than did Price et al. [56]. This suggests that the perception of wearable cameras is not fixed, and depends on the context and prior experiences of both wearers and bystanders. Perceptions of wearable cameras can change over time as the sales of wearable action cameras continue to increase [64], and wearable cameras are used in more cities and countries for a range of purposes, such as increasing accountability in policing [11] and other institutions [41].

In this study, we aimed to understand factors that prevent researchers from capturing authentic behavior using wearable cameras in order to provide potential solutions for the research community. Previous studies have either focused on ego-centric camera designs such as a face-forward wearable camera worn around the neck [5, 27, 42, 45, 47, 51, 56, 57] or wearable glasses equipped with a camera [13, 36, 37, 45]. There are researchers who use

non-ego-centric cameras, what we call *activity-oriented cameras* (see Figure 1), such at the shoulder [21, 44, 55] or the wrist [7, 35, 67] to observe human behavior or activity. None report on the effect of such placement on the wearer and to the best of our knowledge, no one has studied the effect of lens orientation and location on the wearer. Activity-oriented cameras are designed to record a specific activity rather than the gaze or the view of the participant, like the ego-centric camera, nor the total scene, like the surveillance camera and may therefore result in differing wearer perception and behavior. Thus, the current work extends behavioral observation research by testing the effect of activity-oriented cameras by manipulating camera and lens positioning and measuring wearer perception. The contributions of this paper are the following:

1. In-depth qualitative analysis of the types and sources of discomfort arising in the context of activity-oriented wearable camera use.
2. An analysis on how the wearable cameras location on the body and lens orientation can impact the wearer's comfort and behavior.
3. A model based on theoretical and empirical findings explaining factors influencing social presence and social stigma in the context of wearables.

We designed a study protocol where we asked participants to don a wearable camera, a Microsoft Band 2 wrist-worn sensor, and a customized neck-worn sensor. As part of future studies, we intend to use the camera as a form of ground truth for building ML models to validate behaviors detected by the wrist-worn and neck-worn sensors; so it was essential to test the participant's willingness to wear the camera simultaneously with other wearables. We had three camera designs (chest, wrist, and shoulder). We assigned one camera design to the participants then asked them to engage in activities outside of the lab for 3–4 hours. For the first 90 minutes, they followed a semi-structured protocol designed to immerse them in contexts that might instigate privacy and social stigma concerns, including activities such as drinking in a coffee shop, asking a bystander a question, and using an automated teller machine (ATM). In the remaining hours, they were free to engage in other activities. After returning to the lab, they answered open-ended questions about their experience and the devices. Then we asked the participants to test the two other remaining camera designs while performing more structured activities. At the end, we asked them to participate in a follow-up interview about their experience with the three camera designs. We then provide an in-depth analysis of their response to these questions and a model to explain the factors that influence social presence and social stigma in the context of wearable cameras.

2 BACKGROUND

The use of wearable cameras is not restricted to understanding human behavior in health research. In the domain of law enforcement, police officers use wearable cameras as a tool to monitor behavior and increase accountability [4]. Wearable cameras have also been used by researchers to collect visual observations [6], to understand how people interact with smart watches [43], and to understand food consumption behaviors [49]. In personal applications, this technology allows individuals to capture memorable moments in their lives (i.e., life logging) [79]. The ubiquity of wearable camera use has motivated researchers to extend its utility to timely visual confirmation of behaviors being measured throughout the day.

Researchers naturally evolved to investigate facilitators and barriers of camera use including acceptability of wearing the camera, recording of events continuously, and privacy concerns.

Hoyle et al. [27] studied privacy in the context of life logging by analyzing the images that participants were more likely to share on social media and with whom. Participants reported that an image was considered "sensitive" based on who was present, what was being recorded (e.g., vice or computer screens), and when and where it was recorded (e.g., indoor compared to outdoor). Price et al. [56] replicated the study in the United Kingdom and reported participants having similar concerns regarding sensitivity of what is being recorded, but reported fewer concerns related to sharing images of their computer screens, referring to the content as "normal stuff" Other researchers studied bystander privacy concerns of wearable cameras mounted on glasses and concluded that bystanders wanted to be consented before they were recorded [13]. However, seeking the consent of every individual encountered is neither feasible nor conducive to natural behavior. This challenge inspired technological solutions that addressed some privacy concerns via use of privacy-preserving image processing techniques [16, 38, 72] or frameworks [23, 32, 72].

2.1 Impression Management for Self Presentation

In his book "The Presentation of Self in Everyday Life," Goffman [20] explained social life through a dramaturgical lens. He described life as a play with people as actors. Accordingly, there are many stages on which we can perform, (e.g., school, work, or beach). Through our social interactions, we learn how to perform on each stage in a way that maintains a certain impression about ourselves in front of an audience. The performed persona comprises the appearance (how someone looks) and manners (how someone acts), which can be communicated through verbal and non-verbal cues to present an identity that the audience can interpret. Therefore, the actor will always try to perform in accordance with the impression that he or she wants to convey to a particular audience. However, wearables (especially new and unfamiliar ones) can disturb this performance, causing uncertainty for the wearers about the impressions others will have about them, affecting how people manage their impression, which can change how they behave. Moreover, if the impression derived is perceived by the wearer to be negative in nature, then wearables could increase perceived social stigma.

Goffman also explained that after the performance stops and the actors start to be themselves, then they are in what he termed the *backstage* where they are alone with no audience present; comparable to the most natural or authentic self. Actors try very hard to separate the frontstage from the backstage persona, and they often fear intrusion or the leakage of sensitive information so the frontstage persona is not discredited. The introduction of wearables changes how people manage their impression because wearables can generate a social presence (the feeling that someone is there) and social stigma (disapproval of a person), in absence of an in-person audience, thereby transforming the front and backstage into new unfamiliar stages, which may result in inauthentic behavior.

2.1.1 Impression Management and Social Presence.—

The presence of an audience (social presence) affects people's behavior. Social presence, can be explicit

(someone is physically there) or implicit due to the presence of a device or platform. This sense of social presence can be beneficial or detrimental. For instance, Rompay et al. [75] found that a security camera also implied social presence, where it increased pro-social behavior in terms of helping others, creating bias in the data collection. In the domain of technology-based learning, creating a sense of strong social presence is desired because it improves instruction [22]. Phelan et al. [54] showed that social presence can be offset by increasing the trust in the data collector, as well as by emphasizing that social presence is not dichotomous, i.e., instead of existing or not existing, it lies on a continuous scale of strength, and different levels of social presence can outweigh one another.

Cultivating any sense of strong social presence is not desirable when the intention is to understand authentic behavior. For example, Risko et al. [62] showed that eye trackers can influence the looking behavior because of the perceived social presence. Social presence also has an influence on other human behaviors such as eating [25] and consumer behavior [12]. Therefore, in the context of behavior observation, social presence may create bias in the data collection if it alters the authentic behavior.

2.1.2 Impression Management and Social Stigma.—

An individual's style of dress creates a particular impression, which can alter how others behave or interact with them [31]. Thus, wearables affect impressions and they influence the wearer's ability to effectively manage their impression. How others change their perceptions due to the presence of the wearable is important, and if the impression is one that discredits the intended impression of the wearer, the wearer will be transformed into a "stigmatized" individual who does not receive full social acceptance, unlike the non-stigmatized self. When the self becomes stigmatized and the source of stigma is not corrected, the wearer will engage in more impression management, thereby resulting in behavior that differs from that of the non-stigmatized self. Goffman explained that the stigmatized self will not aim to correct the stigma by presenting the self as desirable (challenging the norm), but instead will avoid situations that lead to this stigmatization. This form of impression management may make people abandon their wearables in specific contexts or avoid wearing them altogether.

Wearable designs that do not resemble current mainstream devices can bring more attention to an already stigmatized individual (e.g., a person with a disability). In the context of assistive technology, Shinohara et al. [66] proposed an approach where designers should incorporate assistive technology into existing devices to avoid giving an impression of incapability (for example the screen reader accessibility feature found in mainstream mobile phones rather than limiting the user to a specific phone designed for people with visual impairment). As with the design of wearables, the gesture used to interact with the wearable can also affect the impression conveyed. For example, Profita et al. [58] found that female participants felt it is socially unacceptable to interact with a wearable located on the collarbone using a circular gestural pattern because it might convey an impression of someone trying to bring attention to that body part.

3 METHODOLOGY

3.1 Ethical Considerations

This study was approved by the Northwestern University Institutional Review Board. As part of the informed consent process, we explained to potential participants that they were not forced to wear the devices and they could remove them at any time they felt uncomfortable. They were also provided with an information card to explain the purpose of the study, as well as the principal investigator's name and contact information, which is similar to the approach used by Nebeker et al. [47] and recommended by Kelly et al. [32]. Participants had the option to give this card to bystanders if they were asked about the devices. Despite this precaution, we did not receive any calls from bystanders.

3.2 Recruitment

Participants were recruited using ResearchMatch [61], an online platform that matches researchers with participants. We also posted flyers around Northwestern University (Chicago and Evanston campus). Eligibility criteria comprised age of 19 to 63 years and a body mass index (BMI) above 19. We conducted the distribution of recruitment equally across individuals who were normal, overweight, and obese according to their BMI. We also ensured equal gender representations within each stratum. We aimed to recruit participants across different genders and BMIs to capture representative responses. To ensure that we captured eating events, we excluded participants with a low BMI (less than 19).

3.3 Procedure

Prior to the main study, the experiment was piloted with three students of varying BMIs. The feedback from the pilot test allowed us to refine our camera instruction manual and our questionnaires as well as incorporate suggestions for various neck straps. In Table 1, we list the experimental procedure.

3.3.1 Informed Consent and Training.—After completing the online screening process to determine eligibility, the participants were scheduled to attend the lab for the informed consent process. In the consent form, we informed participants: "The research labs ultimate goal is to be able to passively detect eating-related behaviors using wearables. In order for us to detect eating passively throughout the day, we need to understand people's willingness to wear these sensors in different scenarios. This study will help contribute to our understanding of wearable solutions that people are likely and unlikely to wear. We are not testing or judging your behavior but instead we are testing the devices." Since we were interested in recording their eating episodes, it was important that the participant perceived a non-judgmental attitude with respect to their eating episodes. The researchers showed the participants how to wear the assigned camera and how to remove it, as well as how to turn on and shut off the camera. The participants practiced wearing the camera and turning it on and off before starting the experiment. After the informed consent process, they were asked to complete questionnaires about their eating habits [24, 40, 69, 76], social media usage, and their attitude to privacy [8].

3.3.2 Wearable Devices.—The wearable devices employed in this study were used for eating detection, but they could also be used to detect other events. The wearables comprised a wearable camera, Microsoft Band 2 (mBand2) wrist-worn sensor, and neck-worn sensor (figure 2). We did not test the camera itself independently of the other sensors because we were interested in capturing visually validated ground truth behavior while mapping it onto other wearable sensor data. Thus, we wanted to understand their willingness to wear the camera while wearing these other sensors (which will be used in future studies to characterize eating behaviors by analyzing chewing and feeding related activities). Only two participants reported concerns regarding the size of the neck-worn and wrist-worn sensor (being too small or tight). However, the wearable cameras elicited concerns from almost all participants. As a result, we focus our analysis on concerns related to the wearable camera.

We assembled a wearable camera using an Amcrest QSD-721[1] video camera because it can be operated for more than 12 hours on a single charge and it is rechargeable. We attached a 180-degree fish-eye lens to the camera to increase the video coverage captured and we then mounted it on a wearable strap. The camera could be turned on and off by clicking a button. A small LED light indicated whether the camera was on or off. The camera time and other settings could be adjusted using software (provided by the manufacturer). Videos were stored in 20-minute intervals on a 64 GB SD card.

We designed three versions of the wearable camera for three body positions: chest, shoulder, and wrist. The chest design was mounted using the GoPro chest strap[2], which centered the camera around the chest. The chest camera lens was rotatable, which allowed us to adjust the angle of the lens for each person. The lens was pointed at the face to capture any gesture toward or near the mouth as well as jaw motions. The shoulder design was mounted using the GoPro shoulder strap[3], where the camera rested on the participant's chest near the non-dominant hand with the lens pointed toward the participant's dominant arm. This allowed the camera to capture the participant's mouth, dominant hand gesture, and the meal plate. The wrist camera was mounted on the participant's dominant forearm at 2.5 cm away from the wrist with the lens pointed parallel to the thumb using a compression wrist strap. These options allowed us to study whether the location of the wearable camera affected the user's perceived burden and the quality of the ground truth images collected (whether they captured the intended feeding behavior). The participants only wore one camera at a time. The design of the camera was assigned randomly by strata (divided by BMI and gender). Camera design assigned was also counterbalanced in each stratum.

3.3.3 Experiment in the Wild: Structured and Unstructured Activities.—The participants were asked to engage in structured and unstructured activities outside the lab. The structured activities were designed to place the participants in scenarios that might impose a burden or raise concerns due to surveillance or social discomfort. The structured activities were: (1) walking on Michigan Avenue (a busy street in Chicago) and asking a stranger for directions, (2) eating at home or in a restaurant, (3) going to a coffee shop and

[1]Amcrest QSD-721 https://amcrest.com/qcam-qsd-721-hidden-camera.html
[2]GoPro chest strap https://www.amazon.com/GoPro-Chesty-Chest-Harness-Official/dp/B0025UEQQW
[3]GoPro shoulder strap https://www.amazon.com/Hapurs-Shoulder-Harness-Supports-Session/dp/B0111SP0XW

ordering water or a drink, (4) going to the bathroom, (5) checking email, and (6) using an ATM. After they completed the structured activities, the participants were instructed to continue wearing the devices for at least two more hours while performing any activity of their choice. The study was structured in order to capture responses in specific contexts of importance to our research, and that are known to increase the burden when wearing the wearables. This experiment was designed to be short in order to prevent self-reflection or formation of coping behaviors.

3.3.4 Post-Experiment Questionnaires.—After returning to the lab, the participants answered open-ended questions about their experiences while wearing the device in the wild (adapted from Nebeker et al. [47]). These questions were used as a base for the semi-structured interview performed at the end of the study.

3.3.5 Other Cameras.—Participants were asked to try out the two remaining cameras that were different from the one assigned to them earlier. They were asked to engage in a short structured activity that included going to the supermarket, using a computer, eating a snack and looking at themselves in the mirror. After trying out each camera design, they were asked open-ended questions about each camera.

3.3.6 Video Review Process.—The participants were asked to look at the videos they captured with each wearable camera and to delete any segments that they did not want to share with the research team. (No one deleted any segments; however, one participant requested removal of the audio.) The participants were instructed to indicate any segments that they wished to delete by marking the start and end of the segments (shown in red in Figure 3) in a video reviewing software provided to them. We also asked the participants to mark the start and end of at least one activity from the structured activities assigned to them. This task was designed to help us see if it was easy for the participants to use the video reviewing software to find an activity segment. Because it has been shown that the concerns of participants can change in situations where they have personal involvement with the data collected [59], participants were asked questions about the video they viewed, whether it was what they expected, and whether they had any further comfort or privacy concerns after viewing the video collected by each camera design. To ensure that they reviewed the footage, we asked them to mark the start and end times when they were eating.

3.3.7 Interview.—At the end of the procedure, the participants were subjected to a semi-structured interview that lasted between 15 to 30 minutes. We probed the participants about the answers they provided in the open-ended questionnaire to obtain further insights into how the participants defined comfort and burden with respect to wearables. Whenever a participant mentioned an encounter with a bystander that noticed the camera, we asked them to elaborate more on that encounter. Whenever a discomfort is mentioned and not further elaborated on (such as just saying “it was weird”), or if the discomfort was not clear, we asked the participants to elaborate further.

3.4 Participants

The procedure was performed by 24 participants (see Table 2). The average age of the participants was 35 years (σ = 13.4) with 13 female and 11 male. The majority of the participants (n=21) had a social media account, which they report to be somewhat private (n = 13). We divided the 24 participants into three groups and assigned one of the camera designs to them (shoulder, chest, or wrist). We ensured that each group was balanced by gender and BMI (normal, overweight, and obese). All participants reported completing the structured activities except two participants who did not have an ATM card with them. The researchers did not follow the participant to ensure compliance with the structured activity. However, one author reviewed the participants videos and confirmed structured activity compliance. Table 3 shows the unstructured activities participants performed along with the location where it was performed. This table was generated by researchers viewing the participants' videos and by the location references used by the participants in the questionnaires and interview. Participants were compensated with $20 (USD) in cash at the end of the experiment. In addition, parking validation was provided if necessary.

3.5 Analysis

Qualitative data were analyzed using thematic analysis [3]. First, two authors read all transcripts during an open coding period and independently generated code lists. Then, they met to create an initial codebook informed by our research questions. The codebook comprised lower-level codes sorted into themes (see Table 4). The initial codebook was first implemented on a randomly selected subset of 6 participants' data, which were coded independently by both coders using NVivo 11[4]. The coders met to resolve discrepancies and made final refinements to the codebook. One author then coded the whole dataset and the other acted as a consensus coder. Any conflicts in the coding process were resolved by discussion.

3.6 Video Reviewing Software

The camera saved a separate video file every 20 minutes, so we developed software to facilitate the viewing and labeling of the videos recorded. The software allowed participants to load and view the collected video segments in a fast and user-friendly manner. Figure 3 shows an example of videos loaded and marked by a participant.

4 FINDINGS

Through survey responses, participants indicated a moderate degree of discomfort and change to their authentic behavior. Fourteen participants reported taking off or covering the camera, other than when they were instructed to do so in the structured activities. Most participants covered the camera for a few minutes (verified by their reports), three participants reported taking off the device for about 20 minutes due to: 1) device physical discomfort at the end of the study; 2) going to the doctor, and 3) volunteering with kids. Thirteen participants reported that the camera made them uncomfortable. When asked if the camera changed how they normally go about their activities, participants reported that it

[4]NVivo 11 https://www.qsrinternational.com/nvivo/home

changed how they ate (n=5), how they socialized (n=2), and how they felt in public (n=11). Two of the participants (P17 and P18) did not report any type of discomfort with the devices (it could be because of their age as we noticed that older participants had less concerns with the camera). While 16 participants said that the video footage was as they expected, one participant thought that it did not record audio, one did not understand why it would be taking a video of her chin in the chest camera and the other mentioned that they thought that the resolution would be higher. It took participants less than 10 minutes to review the video. We further explore these types of discomfort, and questions and opinions about the devices, through qualitative analysis of responses to open-ended questions and interview prompts.

From the coding process, we identified three major types of discomfort expressed by the participant: device discomfort, surveillance discomfort, and social discomfort.

4.1 Device Discomfort

Device discomfort is related to the discomfort that emerged because of the interaction of the wearable camera with the participant's body. Wearers commonly reported concerns related to the physical sensory discomfort such as *"itchy", "tight", "heavy", "bulky", "pressure on your chest",* which was mainly due to the materials used in the wearable camera, the size and hot weather. The second concern relates to the physical constraint that can arise with wearable designs. Physical constraint can affect *"motions of the wrist"* due to the placement of the wearable along with its size in relation to the participant's arm. Also, wearables can exacerbate pre-existing constraints, as mentioned by P10, who reported *"the strap across chest felt inhibiting, already wearing women's undergarment and this didn't feel right."* Lastly, attachment discomfort related to how wearables are attached to the participant's body, as P15 explains: *"Every time I had to use the bathroom, I had to remove the camera which was a painful chore."* Attachment method concerns also emerged depending on the body type and gender, one participant suggested *"it cuts right across my chest which is more uncomfortable. Find a way to move the straps around a woman's chest."* Device discomfort often led to the participants removing the device, or at least changing its position in order to make it more comfortable.

4.2 Surveillance Discomfort

4.2.1 Surveillance of the Self.—

The introduction of the camera in the backstage transformed the backstage into a new type of frontstage because social presence was considered a type of intrusion into the backstage. This led to a feeling of being watched, which often changed the behavior of the participants or created a sense of pressure, making them more conscious of their behavior. P04 explained that:

> "When you carry a camera you feel like someone is watching you. Because you know that your action will be recorded, so you will try to behave yourself. And you feel tight [restricted] and not that normal."

This intrusion led participants to take privacy-preserving actions like covering the camera when entering sensitive information like passwords while using the computer or entering their credit card pin code while shopping.

The camera also appears to have caused an increase in impression management, leading participants to modify their authentic behavior in order to control their impression or prevent harm. The proximity of the camera to the participant's mouth can lead to greater self-consciousness while eating. P09 said that: *"When I was eating, I tried not to look too horrible in the camera."* The shoulder and the chest camera were approximately 10 cm away from the participant's mouth and facing upward toward the participant's face. This atypical angle for camera recording engendered a sense that someone was constantly looking at them while eating next to or across the table from them.

Another form of impression management reported by the participants was related to the need to avoid potential threats caused by surveillance. The participants had concerns about how the video could be used *"against them"* to harm their reputation or to criminalize them. *"I do smoke marijuana pretty frequently with friends, um, and we are all trying to be lawyers even though it is gonna be legal soon and who cares but like no one wants that on videotape.".* The recorded video captures sufficient detail to recreate a scene, thereby making it a strong source of evidence that is difficult to refute. In some cases, participants reported time where they had low awareness of the camera or forgot about it which caused discomfort, meaning they lost control of their impression management or privacy-preserving actions leaving them in a state of uncertainty, which can be burdensome.

Not all of the reports indicated that surveillance had adverse effects. For example, P12 stated that: *"I think it slowed me down, knowing someone would watch the video and see what I was doing."* Despite explaining the correct intentions of the study, some participants believed that we were using the camera in order to intervene rather than a method to capture naturally occurring ground truth behavior. Thus, some participants changed their behavior due to social desirability bias or participant bias, where the participants behaved in a way that would please the researcher by attempting to read between the lines, and endeavoring to glean the intentions of the researcher. For example, P21 explained that: *"It did slightly remind me of being conscious of what I ate and their caloric value."* In addition, P15 reported: *"I was more conscious about choosing healthy foods and my eating style."* We noted that half of the participants with an obese BMI reported a change in their eating behavior.

4.2.2 Surveillance of Familiar People.—

Hiding the camera might convey an untrustworthy impression to others. P07 reported his reasoning about the effects of concealing the camera as follows:

> "If I hide it, that's going to be bad because if people for some reason discover that I have a camera that could record them and that I hide it, they will ask why are you hiding it?…They will think that I'm secretly recording them and there will be some trust lost. I will not trust a person that is secretly hiding it without telling from the beginning."

When a participant referred to discovery, they meant either the discovery of a hidden camera (even if it was turned off) or of a video recording camera. The participants articulated the dilemma regarding whether they hid or showed the device. When people were in a familiar

frontstage, they tended to disclose the existence of a camera, evidently in order to retain the trust of their friends.

Exposing the presence of a recording device to others rather than hiding it was an option that ensured no loss of trust among familiar people. However, there was still a sense of burden when wearing the camera in front of others, as explained by P24: *"I think like I wouldn't want to inhibit their ability to socialize. If I told them, it would change the way we would hang out and you know I don't wanna do that because I value the relationship of being genuine to friends more than I value my ability to stop binge eating."* In this case, announcing the presence of a camera transformed the frontstage into a new heightened frontstage, thereby creating a sense of uncertainty about how one should behave and some actors began to play a new role, which inhibited their ability to socialize effectively This change of roles created discomfort in the wearer, particularly in a familiar frontstage. Even when the actors agreed to the presence of the camera, the participants were constantly concerned about what others thought as P05 mentions: *"they might pretend that they are [comfortable with it] but, for longer time, they will ignore you if you wear it always."*

The lens orientation of the camera had an impact on how surveillance might be perceived among familiar people. P7 explained the concern with the lens orientation of the chest camera and how it can effect the people that he is directly talking to *"I feel like if I am meeting with a friend, my friend will keep on looking at the camera. And even if I told him it is an experiment, it would just stay there all the time… This camera is pointing at a person [bystander] all the time. It's weird. For example, when a friend is looking at their Snapchat, and their camera is pointing at me, I wonder if they are taking a picture or not. It's just camera pointing at you. And I feel like, I would feel like that all the time."* The concern of the orientation of the camera is that if the lens is pointing toward someone it is hard to not think about the fact that the camera is recording.

4.2.3 Surveillance of Strangers.—

Concerns about the privacy of strangers was expressed even though there was no reaction from bystanders. As P10 expressed that she is *"worried about people's privacy, business men/woman were conducting business as business people do and it was none of my/our business."* This is due to the fact that the camera can capture sensitive information about bystanders which might lead the wearer to worry about privacy measurements taken to protect their information. Despite the fact that surveillance is normalized in public spaces, some participants were aware that there are still some people who are against surveillance even when it is used for legitimate purposes, meaning that there will always be a problem of surveillance, for some, in public places.

4.3 Video Attributes Contributing to Surveillance Discomfort

The video recordings provided details that could be viewed by anyone with access to the recordings. Thereby making the participants and their activities open to interpretation, but without giving them a chance to correct the impressions that others might infer regarding them. Also, video records might have sensitive information about the participant that can be abused by others if they had access to the recording. The social presence or surveillance

brought by the wearable camera can be controlled by the clarity, scope, and continuity of the recording.

4.3.1 Recording Clarity.—In the case on the chest and shoulder camera some participants reported that the video quality is not as expected (it was noisier than expected). P5 suggested that it would reduce discomfort to know the resolution of the camera for future participants: *"if they see that the resolution is super bad or super noisy then they might not care. ".* For the chest and shoulder camera it is easier to anticipate the clarity of the recording in relation to distance from the camera because the camera is placed in a fixed position on the body. However, this is not the case with the wrist camera as P07 expressed concerns about the resolution of the wrist camera as *"it clearly focused on [his] computer screen. "*The resolution of all cameras were the same, what differed in the case of the wrist camera is the proximity of the hand, which might result in a clearer image if the hand was close to the object.

4.3.2 Recording Scope.—The orientation of the lens in the case of the chest and shoulder camera constrain the scope of the recording, which can help the wearer manage their impression and privacy. P02 reported the following about the chest camera: *"I think it is also good for privacy because you can clearly tell when the person is eating but you cannot see their face".* The angle of the chest camera was pointed up to the mouth and shows the chin, but the face was not easily identified. P24 further explained that with the chest camera *"if there is no audio recording and it was just looking at me, people would be fine"* showing that the scope of video determined by lens orientation effects how the participant perceives others will feel about the camera and ultimately affects how the participant feels about wearing the camera among others.

In the case of the wrist camera, P01 explained that *"since the camera was more free, more angles were captured so there were more instances for my body and other people to be caught on the footage".* This unpredictability of the scope of the camera might lead to capturing images without the awareness of the wearer, especially since the video is from the perspective of the hand. On the other hand, P07 explained that in the case of the wrist camera, there is more control on the scope of the footage because the camera can be easily moved by moving the hand, *"it's not like I am a subject of something. It's more like okay I'm participating, but I'm also recording what I want. You see, you move it around. You show what you want to show."*

4.3.3 Recording Continuity.—The video camera started recording after the participant pushed the toggle record button, and it only stopped when the participant pushed the button again. While operational, the camera recorded continuously so the participant needed to constantly think about whether they should shut the camera off or remove it, and whether the camera was on or off. This continuity of recording also affected impression management as P04 explained that it might be hard to wear the camera all day but for a limited time of one or two hours per day is fine as he explains: *"Maybe you don't want someone [to] watch you all the day or what you're doing for the whole day. It's your normal life."*

4.4 Bystander Interactions

Participants mentioned that bystanders gave them *"looks"* but only seven participants reported that they were asked about the camera by a stranger (n=3) or someone familiar (n=4). Only three participants actually used the study information card (provided to them) when bystanders asked them about the device. The others just explained that they were part of an experiment without handing out the card. However, there was one participant who mentioned that she kept the card in her hand when she was worried about someone confronting her about the camera.

4.5 Participants Bystander Reported Reaction

Some participants reported that bystanders (especially strangers) gave them *"looks"* or *"double takes"* which made them feel uncomfortable and others were surprised that there was little or no reaction to the camera as *"no one seemed to notice it or have any issues with it."* While analyzing bystander reactions in the case of an actual encounter, participants reported that some were curious about the device where they asked about the device and its functionality and other bystanders showed discomfort regarding the participant wearing the camera. P1 explained: *"I went to volunteer at the school and I had to turn it off because the sponsor did not feel comfortable."* She was not surprised from the reaction of the bystander because she understood that she is not allowed to wear the camera around kids without parental consent. P5 had an encounter with his manger where he asked about the camera and the research. He also asked about how we are handling bystander consent. P5 replied to him by stating, *"[I] can delete any part that I think it is not good,"* and his manager replied by saying, *"cool."* Lastly, P22 described talking to a stranger on the street, who told him that she *"can't be recorded cause of [her] job."* However, we did not receive any calls from bystanders nor did they request deletion of any footage.

4.6 Social Discomfort

While being in public, some reported *"looks"* they received from other people as P02 explains that she *"felt slightly uncomfortable when people would blatantly stare at me or the device."* Another form of discomfort was being self-conscious that they will be called out on wearing the device as described by P11: *"I was worried someone would call me out and ask about it, even though I never saw anyone look at the camera directly."* These feelings can lead to a fear of judgment and confrontation as well as a burden of needing to provide an explanation.

4.6.1 Fear of Judgments, Confrontation, and Explanation.—

The *"looks"* received from bystanders heightened the sense of uncertainty about what others were thinking, which then increased the fear of being judged mistakenly. These stares created a need for the participants to further explain or justify themselves, as stated by P09: *"The double take made me uncomfortable because I would have to explain."* Part of this judgment and conformation comes from concerns about how the participants will be framed because of wearing the camera. Frames related to being a spy, police, or media reporter emerged along with an expression of fear regarding how the device might alarm others and possibly lead to unwanted confrontation. P09 explained that: *"I just think maybe an unnecessary, um,*

confrontation. Ya know, maybe someone saying, I don't want my face being in a camera. What's this for? Are you news or police?"

Thus, some participants were apprehensive about impression management and privacy concerns to the point where they feared confrontation. This can be either a legitimate concern raised about wearing a camera when a participant did not appear to be the type of person who would typically carry such a device, like a police officer or news reporter. However, even with legitimacy and approval, mistreatment might still occur depending on the context. P09 continued by saying that: *"We are in aggressive times right now, we got the whole Trump situation. People are protesting. You have the whole police situation, so, ya know, just safety concerns."* It also might be the case that the wearer does not want other people to know the reason for wearing the device or its association with research. P07 explained that: *"I don't want people to ask me about it. Uh, I mean, why do you have that? Oh well, I have waist problems, and…it's a little personal, ya know?"*

Even when the camera is not recording audio or if it has smart functionality that triggers the context of recording, P24 showed a concern with the chest camera that *"unless I had a sign that says this camera does not record audio there is no way that others will perceive the camera in a different way."* He continues to explain: *"it is all about people perception, so it is like the same problem is that people don't have complete information if there is a way for me to let everyone in the world know that this thing is not recording and for them to believe me then I don't care when you record me. You know? For the issue is what it looks like to people and their trust, so it is like the game theory incomplete information type of thing and the only fix for me is to provide people with complete information, um, or not to let them see that there is a camera at all."* This was an example of a camera design that fails to communicate its functionality (whether it records audio or not) and in this case it will be perceived as a normal camera with functionalities similar to common cameras. In the case of the shoulder camera, P07 explains the orientation of the lens made it *"clear that it's not recording the people I'm talking with"* so he wanted to conceal the shoulder camera with something like a badge because he did not *"want people to look at it."* However, in the case of the chest camera, he articulated that it should not be concealed because it is *"clear that a person will be recorded and if they find out that I'm hiding it, they will think that I'm secretly recording them, and there will be some trust lost."*

4.6.2 Similarity to Threatening Devices.—Few participants also expressed that the device might not be perceived as a camera but rather be perceived as a threating device such as a bomb or a gun. P24 stated that: *"It [The shoulder camera] looks like I was Yosemite Sam and I have a gun. I don't think anyone will wear this if it is visible. You look like a suicide bomber and it [will] weird people up."* What could have explained this response is that at the time of the experiment there were shootings and bombings happening around the world, and so P02 explains that *"some people are just sensitive these days. There's a lot going on. People misunderstand things."* Other than the timing and the context of the experiment, P07 further adds that his ethnicity along with the devices might frame him differently: *"As a person of color, having a package attached to my arm and a coat, may look suspicious. I was worried police will stop me."* Location of the wearable also facilitates the fast emergence of threatening framing of the device as P02 explains: *"When you see like*

people wearing [a] bomb strapped to their chest they're always like right here [referring to the location of the chest camera]. I don't know why that's just how they're depicted," and P21 explains that the attachment style of both the chest and shoulder cameras *"may have resembled a holster to some people based on their glances."*

4.7 Normality Factors

Participants did not receive much reaction from strangers, which led them to think of reasons why it was normal to not get any reactions from strangers, like the camera being similar to common devices, device location, and context they were in.

4.7.1 Similar to Common Device.—Because of the prevalence of the wearable action camera, GoPro, P02 explains why she did not receive the reactions she anticipated: *"I also recognize that you know, GoPros are definitely a thing these days so it becomes like other people's perception of cameras like aren't that bad."* Moreover, P09 thought that she can use the GoPro reference in case of a confrontation as she mentions: *"ya know, I was even kind of thinking of excuses in my head too, in case, like they don't want me to hand them anything [referring to the experiment card]. I'll just say, 'Ah it's a GoPro.'".* She then went on to explain that the wrist camera is similar to the iWatch and Fitbit and that *"at glance, it does not look like anything that is threatening."*

4.7.2 Device Location.—A lot of participants mentioned that placing the camera on the wrist will result in the camera being less obtrusive, P11 explains that *"it is common that people wear wrist technology now…which was not used to be the case before but now I think it is not weird that people have a thing on their wrist."* On the contrary, the chest camera was regarded as the most obvious, as P10 mentions: *"The camera was too obvious, located in the center of my chest. I have a big chest and it draws enough attention."*

4.7.3 Context.—The geographic location where the participants wore the devices also influenced the perceived normality of the device perception. P02 explains that she wore the camera in *"a metropolitan area where people are used to seeing all sorts of crazy accessories,"* she felt this was the reason why she did not get a reaction, but felt that if she were to wear it in *"a more conservative area then it would definitely stand out."* Some participants mentioned that the proximity of the hospital to the lab normalized the device, where P04 stated: *"it's pretty normal to wear these strange devices."*

4.8 Camera Type Analysis

Because the participants have tried all of the camera designs, they were able to compare between the devices. We do acknowledge that they wore the first design that was assigned to them more than the other designs, but using the mini-experiment for the two other designs, they still had to go to a public place (i.e., the supermarket). Below we summarize the common themes that emerged while comparing between the three devices.

4.8.1 Chest Camera.—The chest camera was *"front and center"(P14), "conspicuous"* (P10) and *"too obvious that I am wearing a camera"(P11)* and in most cases, it was framed as a camera. However, there are some who mentioned that it is *"more focused on me"(P21)*

which might *"not alarm other people"(P24).* Only P9 mentioned that it is *"hard to distinguish where you are in the footage"* because she can only see *"a ceiling and a chin."* The main drawback of this camera was its visibility on the body.

4.8.2 Shoulder Camera.—The shoulder camera was also regarded as *"obvious on the body"(P01),* and easy *"to see for other people"(P14).* For the shoulder camera, the framing of this device as a camera was not as clear as it was for the chest camera, probably because of its location. Device framing was most variable for the shoulder camera; it ranged from threatening devices like a "gun"(P24) to common devices like a *"phone case"(P11), "walkie-talkies"(P02),* and a *"medical device"(P01).* There was no complaint about the video content of the shoulder camera.

4.8.3 Wrist Camera.—The wrist camera was the *"least obtrusive"(P12), "least intruding and conspicuous"*(P15), and *"least noticeable of all of the cameras because everyone is used to people wearing technology on their wrists"*"(P11) It also provided more control on the recording functionality, since P01 explains that *"it would be easier to cover the camera in the bathroom."* In most cases, the wrist camera was framed as a normal device in comparison to the other devices due to the location that leads to framing it as *"wearing a watch"(P15)* or *"carrying case for an iPhone"(P9).* One of the drawbacks of the wrist camera was video clarity; participants noted the *"video quality was bad because when I walk I swing my arms" (P02)* and *"all the swaying of my hand would make it hard to watch"(P11).* The video content also had *"less focus"* which can make *"it very hard to find eating moments."(P03)*

5 DISCUSSION AND IMPLICATIONS

We show that wearable cameras often lead wearers to experience surveillance discomfort and social discomfort. Discomfort or concerns related to surveillance were expressed regarding not only surveillance of oneself but also surveillance of familiar people (like friends or coworkers) and strangers. These concerns arise due to the "sense of being watched," which we refer to here as perceived social presence. In the context of what Goffman refers to as the frontstage (among strangers or familiar people) and backstage (regarding the self only), a new type of social presence transformed both stages into more public arenas. The presence of an additional audience can require the participant to engage in impression management and privacy-preserving action for the self and others. Consistent with studies on ego-centric cameras[52, 56], in the frontstage, participants worried more about being stigmatized, confronted, and attacked because of the camera.

Our results revealed potential factors that can mitigate surveillance concerns and social discomfort for activity-oriented cameras, including the affordance of the device recording suggested by the lens orientation and the location of the wearable camera. Affordance is a relational property that is directly perceived, independent of the actor's needs, in both natural and cultural environments [19]. The concept of affordances brought by Norman [53] to the HCI community was that of perceived action possibilities, and has been frequently used to understand screen-based graphical interaction. A good design is a design where the perceived affordances are clear and visible, thereby making uses of icons, text, and metaphor both easy and obvious. In the case of wearables, both perceived and real affordances exist.

Rapp et al. [60] suggested that the materiality of the wearable itself can be used to impact affordances in self-tracking wearables. For cameras, affordances, especially those involving what it can record, can be incorporated in camera design, to enhance acceptability and proper use of the device. For example, for the doorbell camera, one of the factors that leads to the acceptance of such cameras is its position and lens orientation [30]. Notably, this case extends Hutchby's [29] interpretation that affordances are constrained by the materiality of the object and suggests that the position of the camera and lens orientation also constrains affordances regarding what the camera can record. Therefore, changing the design of the wearable camera from the ego-centric position to an activity-oriented design can expand or constrain the affordances of the camera recording, which will affect the perceived social presence and social stigma. In Figure 4 we introduce a model that explains factors that can influence social presence and social stigma in the context of wearable cameras, and the next sections expand on the details of this model.

5.1 Surveillance Discomfort and Social Presence

The surveillance discomfort that wearers experience arises from the degree of perceived social presence that the camera conveys through the medium in which data are saved. This objective and potentially detailed data provides less space for subjective interpretations aimed at preserving a positive self-perception. Social presence transforms the backstage into a new type of frontstage, leading to a greater use of impression management behaviors. On the frontstage, this additional social presence is, in effect, introducing a new audience to a stage that is already shared with others. This new audience may or may not be visible to others. If the new audience is not visible to others, it can be considered a form of betrayal of trust, whereas if it is visible, it creates a burden on the people surrounding the wearer, as they too may engage in impression management actions. Further, this presence can create an awkward situation for the wearer, who now feels a need to explain the device and engage in an uncomfortable and possibly threatening conversation. Reducing social presence can reduce surveillance discomfort. As will be discussed in the next section, the location of the wearable camera and lens orientation can lower surveillance discomfort with minimal effort in comparison to the ego-centric camera.

5.2 Factors Affecting Social Presence in the Backstage or a Familiar Frontstage

5.2.1 Type of Audience that can Potentially Have Access to the Data.—

Prior work on lifeloggers' privacy concerns by Hoyle et al.[26, 27] and Price et al.[56], focused on understanding sharing of images captured by the camera to groups related to the wearer (such as close friends and family, co-workers and classmates) and to the general public. Participants had control over this sharing and accordingly could determine the amount of impression management or privacy-preserving action needed. However, in these studies, the participants also knew that in reality the images collected will never be distributed and will remain within the researchers' control, which could have influenced their deleting decisions (i.e., engaging in less privacy-preserving or impression management actions). Bystanders known to the participant also seem to have trust in the research institute and the wearer when it comes to surveillance. For this reason, participants in both our study and in the Price et al. study were less worried about recording the screen of their phones or computers.

Nevertheless, both studies show that even when in a research study with known privacy and confidentiality measures, people engage in impression management activity.

5.2.2 Data Collected Attributes.—Consistent with Nguyen et al. [52], who showed that people appreciated that SenseCam did not have audio and did not continuously capture images, we also show that in our case, audio was considered a greater concern than video. Audio is a recording medium that can result in a great amount of perceived social presence, because it is hard to control the scope of recording. In this case, social presence is strong because the amount of detail captured is similar to someone with whom the participant is very familiar or intimate. In contrast, an intermittent capture resembles people passing, allowing for more vagueness. Similar to us, Nebeker et al.[47] show that the low resolution of SenseCam made the participant feel less surveillance discomfort because it did not allow capture of detailed information. Fewer details reduce social presence, therefore allowing more subjective interpretation of any captured event. In some cases, the detailed capture of information can influence self-perception, which might cause discomfort for the wearer. To this point, Price et al.[56] mentioned that some people might be comfortable with wearing the camera, but show discomfort in reviewing their behaviors like eating and playing games. Due to this effect, the camera can be used as an intervention for unhealthy behaviors. However, if intervention is not the intention, then the data attributes should not be detailed during the data collection phase (e.g., have participants review the data at the end of the study).

5.2.3 Device Recording Affordances.—Similar to the ego-centric camera, in cases where participants wanted to limit the recording scope, they covered the lens or took off the camera. However, we showed that lens orientation had an impact on device recording affordances. For some participants, the design of the chest camera with the lens pointing toward the mouth gave them comfort that the activity was shown but not their faces. It also gave others comfort to signal that the scope of the recording did not include bystanders - “If it is looking at me and there is no audio I am fine.” In the wrist camera, we show that participants perceived more control on the recording scope, and felt less like the subject of an experiment than the chest camera. Mounting the camera on a lanyard rather than a harness can provide greater control of recording scope, too, since people can easily flip the camera or hide it under their shirt.

Current techniques for reducing the unnecessary surveillance of the self and bystander include image degradation [14], limiting data accessibility [45], and automated detection and removal of screens [38] and bathrooms [70]. These efforts can reduce perceived social presence, but only if they are effectively communicated to the wearer and the bystander. When implementing such techniques, people may have to see the data to be able to judge the degree to which they should worry about the surveillance. However, we show that device recording affordances controlled by device location and lens orientation can reduce the social presence without the need to know detailed information about the functionality of the device. This easiness of knowing the device recording affordances is especially important when considering the camera’s presence on the frontstage, where bystanders have less opportunity or willingness to learn about device functionality.

5.3 Factors Affecting Social Presence in the Frontstage

5.3.1 Device Recording Affordances and Device Framing.—Nguyen et al.[52] showed that bystanders would accept SenseCam if there were a valid reason for its usage. However, like Nguyen et al., we show that for certain designs like the chest camera it might be difficult to frame the camera as having a legitimate or valid purpose, so as to not alarm bystanders or increase perceived social presence. Also, because of the prevalence of wearable cameras, we noticed different framing by the wearer of the camera, as some participants were afraid that others would think that they are police or news reporters. To avoid such misframing that could lead to bystander misinterpretation (that the wearer is trying to record others), the participants concealed the camera so it would be less noticeable to others, thereby mitigating the bystanders concern of increased perceived social presence. Participants also indicated that the device recording affordance can be modified by the device location and lens orientation to match the intent of recording (the participant's activity). In the frontstage, it is especially important that recording affordances match the intent of recording so as to reduce social presence and stigma when among bystanders.

5.3.2 The Type of Audience and Data Attributes Do Not Effect the Social Presence in the Frontstage.—In the frontstage, we note that the type of audience that will be viewing the recording and the attributes of the data collected does not matter in establishing social presence. An assurance from the researchers about how data is handled during research or how it can be processed to ensure privacy has an effect on the wearer, but it will not have the same effect on the bystander unless this information is being communicated to the bystander. Previous efforts to gain bystander trust of recording devices include "issuing the device," displaying a legitimate sign recognizable to bystanders [52], or creating mechanisms where bystanders can opt out [13]. Implementing such efforts requires an immense amount of resources, which a single institute, much less a single researcher, does not possess. Therefore, the data factors that we show in the model (see Figure 4) do not have an effect on the social presence among strangers. In contrast, as shown by the model, activity-oriented cameras can more easily communicate the intent of the recording to bystanders and lower the social presence in the front stage by controlling the affordance of the recording and the framing of the wearable camera.

5.4 Implications Pertaining to Reducing Social Presence

5.4.1 Reducing the Amount of Unnecessary Information Collected Using Camera Recording Affordances and Technological Approaches.—Collecting more information than necessary imposes an unnecessary burden on the participants, which can lead to coping behaviors that might prevent the collection of authentic behavior. Therefore, it is important to plan the type of information that needs to be captured and thereby utilize the camera recording affordances manifested in the device location and lens orientation to focus on capturing the activity of interest. We showed that in the case of the wrist camera, the scope of recording depends on the movement of the wrist, and this camera captures a greater scope than the chest camera. Therefore, the technical approaches to minimizing data collected (like reducing the resolution, blurring out faces, etc.) are still desirable to restrict recording scope. The combination of using both camera recording

affordance and technical approaches will provide more assurance to the bystander that they are not the focus of the recording.

5.4.2 Lowering the Perceived Social Presence Calls for Extra Technological Measures to Ensure Privacy.—We would like to note that lowering perceptions of social presence may not resolve actual threats to privacy. Activity-oriented cameras collect data from an angle that is atypical, which can make it harder for the wearer to visualize the consequence of the information collected, creating an illusion of privacy [48]. Therefore, researchers should not rely on only wearers' judgments about data sharing to make decisions about incorporating technological measures to preserve the privacy of users and people around them.

5.4.3 Ecological Momentary Observations instead of Continuous Observation.—Assessments of human behavior based on natural observations are difficult to administer, and thus researchers have tended to rely on self-report questionnaires for many years. However, these questionnaires are affected by recall bias because they are usually not administered at the same time as the events occur. The introduction of the Ecological Momentary Assessment (EMA) method has changed the way researchers assess human behavior because it allows them to capture near real-time self-report responses from participants triggered by an event, activity or a context. In obtaining self-report data related to activities, Vaizman et al. [74] have shown that incorporating simple online machine learning models that predict activities can provide further detailed subjective description of the participants activity. Observational studies that require visual confirmation should utilize machine learning models and other technical means to collect Ecological Momentary Observation (EMO) instead of continuous observations; that is, a momentary capture should be triggered based on an event, activity, or a context. For example, a camera on the wrist may trigger the capturing of an event, like eating, when there is a high probability of a certain activity (such as a hand gesture to the mouth). EMO will produce less data and minimize the burden of data management on the participants and the researchers. Furthermore, masking the study aims can further improve the understanding of multiple human behaviors, beyond the intended behavior of eating, such as activity, sleep, and the environment, which may ultimately reduce the effects on perceived social stigma by influencing the awareness of the purpose of the study.

5.4.4 Smart Video Review Software to Ease the Video Viewing Process.—As we showed in our results, some participants had trouble viewing the video from the wrist camera since it was moving and swinging with the hand movements. In the case of the chest camera, we show that in some cases participants were not able to identify the context of the recording because the camera was pointing up toward the mouth. To enable more control, other sources of data like GPS, time, and sensor data can be utilized to help in navigating the recording. Similar to Price et al. [56], we found that the participants voiced discomfort about watching themselves eating (although the study by Price et al. was not related to eating). Video reviewing can serve as an unintentional reflective intervention, which should be avoided (during data collection) if the aim is to capture authentic behavior. To mitigate this concern, participants can be permitted to view the data at the end of the data collection

period. Smart video review software can also be utilized to ease reviewing data at the end of the study.

5.5 Social Discomfort and Social Stigma

To collect useful data that reflects the wearers' authentic behavior, it is essential that the wearer not face substantial social discomfort. Goffman's example of the "framing trap" is a useful concept to consider when evaluating wearable design. As the self is a product not only of a person's actions but also how others frame those actions; in cases of uncertainty or ambiguity about how to act, people will make judgments about others that are inaccurate, negative, and cause socially uncomfortable situations. The judged person will not know how to defend himself against this misframing, leading to what Goffman explains as the "framing trap." An example of this framing trap is what participants feel when wearing a camera, especially an ego-centric camera. If a bystander does not know the intentions of the wearer, it does not matter if the camera is being used for a "valid" purpose, or if it is a smart camera able to post-process the images and remove bystanders. Therefore, even if the wearer knows that measures are being taken to mitigate privacy concerns, they still feel the social discomfort arising from being trapped in the frame of being someone wearing a camera (potentially with an undesirable purpose), especially in the case where the lens is facing outward toward bystanders. Participants and researchers cannot change how others will immediately frame the camera, so they instead engage in methods to reduce potential harm to participants by explaining to them how to react to confrontation, providing them with resources (like the card that explains the study). Due to this framing effect, wearers will often choose to engage in impression management actions, similar to a stigmatized person. They will either withdraw from certain places and activities, or even hide or remove the camera. Thus, it is important to ensure that design features of the camera do not activate a negative framing of the camera on the part of bystanders, through factors such as device recording affordances and device framing.

5.6 Factors Affecting Social Stigma

5.6.1 Device Recording Affordances.—When the device is framed as a camera, device recording affordances can increase or decrease social presence in the front stage. We show that the location of the wearable along with the orientation of the lens in activity-oriented camera shifts the focus from capturing participant gaze or a field of view focused on the bystander to that of the activity being performed. This affordance of the recording that is evident in the shoulder and wrist camera provided greater participant comfort than that of the chest camera. If the camera is noticeable and its affordance as a recording device does not communicate the intentions behind the recording, then perceived social stigma increases due to the increased social presence in the frontstage.

5.6.2 Device Framing.—We show that by changing the location of the wearable camera along with the orientation of the lens, we were able to change the framing of the camera from that of being similar to a medical device or common technology to that of a threatening device. If framed as a camera, the device can result in social stigma by increasing social presence on the front stage. However, social stigma can arise even when the device is not framed as a camera - if, instead, it is mistaken for a threatening device. How the wearable is

strapped to the body, its visibility, device color, the context in which the wearable is used, attributes of the wearer, and the political events happening at the current time can all impact device framing. Embedding the activity-oriented camera in everyday devices can reduce the stigma that comes with any misframing.

The focus of the activity-oriented camera is on the activity itself; it is not meant to reflect the gaze or the perceptual field of the wearer (like the ego-centric camera) nor to monitor a specific place in the environment (like surveillance CCTV camera). Thus, activity-oriented cameras appear less focused on the bystander and environment than other types of cameras. In this case, the dilemma of hiding it or showing it is not the same as other camera types, especially if the privacy of the wearer and the bystander is preserved. In a similar manner, people do not warn their visitors that their Alexa device or their Microsoft Kinect device on top of the TV is recording them.

5.7 Implications Pertaining to Reducing Social Stigma

5.7.1 Avoid Uncertainty about the Device.—In the cases where the lens of the camera is not visible to others, there will be uncertainty about the nature of the wearable device. This uncertainty will allow for different frames to emerge from wearers or bystanders based on the device appearance and the context. In some cases, this framing may not be harmful, likening the camera to a medical device, and in some cases it will lead to dangerous framing, likening it to a holster or a bomb. Researchers can avoid such uncertainty by embedding the camera in common devices, or placing the camera in locations on the body where it is common to see devices strapped, like the wrist and the arm.

5.7.2 Utilize Device Recording Affordance.—If the lens of the camera is visible, then the recording affordance of the device should be altered to be perceived as non-threatening to the bystander in order to avoid the traditional camera framing trap.

5.7.3 Test the Device in Different Contexts.—Our results show that activity-oriented cameras can be framed as threatening devices depending on the context, and current events. A participatory design approach to activity-oriented cameras can help researchers understand and reduce potential negative framing.

6 THREATS TO VALIDITY AND LIMITATIONS

This study had several limitations. Not all of the participants went home with the devices. In order to capture more concerns that emerged in the backstage, the experiment should have lasted the whole day. We captured no baseline measurements of the behavior of the participants while wearing the device to compare with their behavior without it because we focused on the responses to the interview questions to identify potential actions that could be construed as coping behaviors. In addition, by telling the participants that they could show the study information card to those that asked about the device, we might have primed them to think something might happen to warrant other people asking them about the device. Also, wearing the other two sensors may have influenced the participants' thoughts regarding their willingness to wear the wearable camera, although previous studies have shown greater concern when wearing a camera than the burden of wearing other non-audio

and video-based wearable sensors [9]. We minimized the effects of the wrist-worn sensor by using a commercially acceptable one, and the effects of the neck-worn sensor by embedding it into mainstream-type necklaces (sport-based necklaces, throat microphone, and fashionable jewelry) and allowing the participants to select the one they were most comfortable wearing. Finally, asking the participants about their BMI and eating habits at the start of the study might have introduced bias into the study design.

7 CONCLUSION

Wearable cameras are one of the best current tools available for capturing objective, reliable, timestamped, and unbiased data about human activity in the wild. In ego-centric camera studies, it has been shown that the attributes of the data collected play a role in establishing a sense of social presence that can lead to surveillance discomfort. Knowing these factors helped researchers propose potential solutions to lower this discomfort by manipulating the attributes of the data collected (e.g., image degradation, image capture frequency, etc.). We show in our study that for activity-oriented cameras, device recording affordances arise from device body location and the orientation of the lens, impacting perceived social presence, especially in public settings. Technological tools that aim to preserve the privacy of the bystander cannot be communicated naturally to bystanders if the device recording affordance is interpreted within the traditional camera frame (i.e., one that is not privacy-preserving), potentially leading to an increase in the wearer's perceived social stigma and changes to authentic behavior which undermine the study purpose. We propose a model of understanding and possible solutions to reduce coping behaviors that can prevent the capture of authentic behavior.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGMENTS

We would like to thank the participants. We would also like to thank the study coordinators at Northwestern University. The authors acknowledge support by the National Institutes of Health under award number UL1TR001422, and by the Institute of Public Health and Medicine at Northwestern University.

REFERENCES

[1]. Bedri Abdelkareem, Li Richard, Haynes Malcolm, Kosaraju Raj Prateek, Grover Ishaan, Prioleau Temiloluwa, Beh Min Yan, Goel Mayank, Starner Thad, and Abowd Gregory. 2017 EarBit: using wearable sensors to detect eating episodes in unconstrained environments. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 1, 3 (2017), 37.

[2]. Bonetto Margherita, Korshunov Pavel, Ramponi Giovanni, and Ebrahimi Touradj. 2015 Privacy in mini-drone based video surveillance In Automatic Face and Gesture Recognition (FG), 2015 11th IEEE International Conference and Workshops on, Vol. 4 IEEE, 1–6.

[3]. Braun Virginia and Clarke Victoria. 2006 Using thematic analysis in psychology. Qualitative research in psychology 3, 2 (2006), 77–101.

[4]. Brucato Ben. 2015 Policing made visible: Mobile technologies and the importance of point of view. Surveillance & society 13, 3/4 (2015), 455.

[5]. Caprani Niamh, O'Connor Noel E, and Gurrin Cathal. 2013 Experiencing SenseCam: a case study interview exploring seven years living with a wearable camera In Proceedings of the 4th international SenseCam & pervasive imaging conference. ACM, 52–59.

[6]. Chalfen Richard. 2014 'Your panopticon or mine?'Incorporating wearable technology's Glass and GoPro into visual social science. Visual Studies 29, 3 (2014), 299–310.

[7]. Chan Cheng-Sheng, Chen Shou-Zhong, Xie Pei-Xuan, Chang Chiung-Chih, and Sun Min. 2016 Recognition from hand cameras: A revisit with deep learning In European Conference on Computer Vision. Springer, 505–521.

[8]. Chignell Mark H, Quan-Haase Anabel, and Gwizdka Jacek. 2003 The privacy attitudes questionnaire (paq): initial development and validation In Proceedings of the Human Factors and Ergonomics Society Annual Meeting, Vol. 47 SAGE Publications, 1326–1330.

[9]. Eun Kyoung Choe Sunny Consolvo, Jung Jaeyeon, Harrison Beverly, Patel Shwetak N., and Kientz Julie A.. 2012 Investigating Receptiveness to Sensing and Inference in the Home Using Sensor Proxies In Proceedings of the 2012 ACM Conference on Ubiquitous Computing (UbiComp '12).ACM, New York, NY, USA, 61–70. 10.1145/2370216.2370226

[10]. Cordeiro Felicia, Epstein Daniel A, Thomaz Edison, Bales Elizabeth, Jagannathan Arvind K, Abowd Gregory D, and Fogarty James. 2015 Barriers and negative nudges: Exploring challenges in food journaling In Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. ACM, 1159–1162.

[11]. Coudert Fanny, Butin Denis, and Daniel Le Metayer. 2015 Body-worn cameras for police accountability: Opportunities and risks. Computer law & security review 31, 6 (2015), 749–762.

[12]. Dahl Darren W, Manchanda Rajesh V, and Argo Jennifer J. 2001 Embarrassment in consumer purchase: The roles of social presence and purchase familiarity. Journal of consumer research 28, 3 (2001), 473–481.

[13]. Denning Tamara. 2014 In Situ with Bystanders of Augmented Reality Glasses : Perspectives on Recording and Privacy-Mediating Technologies. (2014), 2377–2386.

[14]. Dimiccoli Mariella, Marin Juan, and Thomaz Edison. 2018 Mitigating Bystander Privacy Concerns in Egocentric Activity Recognition with Deep Learning and Intentional Image Degradation. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 1, 4 (2018), 132.

[15]. Dong Yujie, Scisco Jenna, Wilson Mike, Muth Eric, and Hoover Adam. 2014 Detecting periods of eating during free-living by tracking wrist motion. IEEE journal of biomedical and health informatics 18, 4 (2014), 1253–1260. [PubMed: 24058042]

[16]. Fan Mingming, Adams Alexander Travis, and Truong Khai N.. 2014 Public restroom detection on mobile phone via active probing. Proceedings of the 2014 ACM International Symposium on Wearable Computers - ISWC '14 (2014), 27–34. 10.1145/2634317.2634320

[17]. Fontana Juan M, Farooq Muhammad, and Sazonov Edward. 2014 Automatic ingestion monitor: A novel wearable device for monitoring of ingestive behavior. IEEE Transactions on Biomedical Engineering 61, 6 (2014), 1772–1779. [PubMed: 24845288]

[18]. Fortuna Chris, Giraud-Carrier Christophe, and West Joshua. 2016 Hand-to-Mouth Motion Tracking in Free-Living Conditions for Improved Weight Control In Healthcare Informatics (ICHI), 2016 IEEE International Conference on. IEEE, 341–348.

[19]. Gibson James J. 2014 The ecological approach to visual perception: classic edition. Psychology Press.

[20]. Goffman Erving. 2006 The presentation of self. Life as theater: A dramaturgical sourcebook (2006).

[21]. Gouveia Ruben, Karapanos Evangelos, and Hassenzahl Marc. 2018 Activity Tracking in vivo In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 362.

[22]. Gunawardena Charlotte N. 1995 Social presence theory and implications for interaction and collaborative learning in computer conferences. International journal ofeducational telecommunications 1, 2 (1995), 147–166.

[23]. Gurrin Cathal, Albatal Rami, Joho Hideo, Ishii Kaori, Insight Centre, and Data Analytics. [n. d.]. A Privacy by Design Approach to Lifelogging. 1 1878 ([n. d.]).

[24]. Herman Barry K, Deal Linda S, DiBenedetti Dana B, Nelson Lauren, Fehnel Sheri E, and Brown T Michelle. [n. d.]. Development o ft he 7-Item Binge-Eating Disorder Screener (BEDS-7). ([n. d.]).

[25]. Herman C Peter, Roth Deborah A, and Polivy Janet. 2003 Effects of the presence of others on food intake: a normative interpretation. Psychological bulletin 129, 6 (2003), 873. [PubMed: 14599286]

[26]. Hoyle Roberto, Templeman Robert, Anthony Denise, Crandall David, and Kapadia Apu. 2015 Sensitive Lifelogs. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15 (2015), 1645–1648. 10.1145/2702123.2702183

[27]. Hoyle Roberto, Templeman Robert, Armes Steven, Anthony Denise, and Crandall David. 2014 Privacy Behaviors of Lifeloggers using Wearable Cameras. UbiComp '14- Proceedings of the 2014 ACM International Joint Conference on Pervasive and Ubiquitous (2014), 571–582. 10.1145/2632048.2632079

[28]. Hui Kher, Victoria Ng, Richard Shipp, Steve Mortier, Flintham Martin, and Rodden Tom. 2015 Understanding food consumption lifecycles using wearable cameras. Personal and Ubiquitous Computing 19, 7 (2015), 1183–1195. 10.1007/s00779-015-0871-y

[29]. Hutchby Ian. 2001 Technologies, texts and affordances. Sociology 35, 2 (2001), 441–456.

[30]. Iachello Giovanni and Abowd Gregory D. 2005 Privacy and proportionality: adapting legal evaluation techniques to inform design in ubiquitous computing In Proceedings of the SIGCHI conference on Human factors in computing systems. ACM, 91–100.

[31]. Johnson Kim KP, Yoo Jeong-Ju, Kim Minjeong, and Lennon Sharron J. 2008 Dress and human behavior: A review and critique. Clothing and Textiles Research Journal 26, 1 (2008), 3–22.

[32]. Kelly Paul, Simon J Marshall Hannah Badland, Kerr Jacqueline, Oliver Melody, Doherty Aiden R, and Foster Charlie. 2013 An ethical framework for automated, wearable cameras in health behavior research. American journal ofpreventive medicine 44, 3 (2013), 314–319.

[33]. Kerr Jacqueline, Marshall Simon J, Godbole Suneeta, Chen Jacqueline, Legge Amanda, Doherty Aiden R, Kelly Paul, Oliver Melody, Badland Hannah M, and Foster Charlie. 2013 Using the SenseCam to improve classifications of sedentary behavior in free-living settings. American journal of preventive medicine 44, 3 (2013), 290–296. [PubMed: 23415127]

[34]. Kerr Jacqueline, Patterson Ruth E, Ellis Katherine, Godbole Suneeta, Johnson Eileen, Lanckriet Gert, and Staudenmayer John. 2016 Objective assessment of physical activity: classifiers for public health. Medicine and science in sports and exercise 48, 5 (2016), 951. [PubMed: 27089222]

[35]. Kim David, Hilliges Otmar, Izadi Shahram, Alex D Butler Jiawen Chen, Oikonomidis Iason, and Olivier Patrick. 2012 Digits: freehand 3D interactions anywhere using a wrist-worn gloveless sensor In Proceedings of the 25th annual ACM symposium on User interface software and technology. ACM, 167–176.

[36]. Koelle Marion, Ali Abdallah El, Vanessa Cobus, Heuten Wilko, and Boll Susanne CJ. 2017 All about Acceptability?: Identifying Factors for the Adoption of Data Glasses In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM, 295–300.

[37]. Koelle Marion, Kranz Matthias, and Moller Andreas. 2015 Don't look at me that way!: Understanding User Attitudes Towards Data Glasses Usage In Proceedings of the 17th international conference on human-computer interaction with mobile devices and services. ACM, 362–372.

[38]. Korayem Mohammed, Templeman Robert, and Chen Dennis. 2016 Enhancing Lifelogging Privacy by Detecting Screens. (2016), 10–15.

[39]. Lichtman Steven W, Pisarska Krystyna, Berman Ellen Raynes, Pestone Michele, Dowling Hillary, Offenbacher Esther, Weisel Hope, Heshka Stanley, Matthews Dwight E, and Heymsfield Steven B. 1992 Discrepancy between self-reported and actual caloric intake and exercise in obese subjects. New England Journal of Medicine 327, 27 (1992), 1893–1898. [PubMed: 1454084]

[40]. Lowe Michael R, Butryn Meghan L, Didie Elizabeth R, Annunziato Rachel A, Thomas J Graham, Crerand Canice E, Ochner Christopher N, Coletta Maria C, Bellace Dara, Wallaert Matthew, et al. 2009 The Power of Food Scale. A new measure of the psychological influence of the food environment. Appetite 53, 1 (2009), 114–118. [PubMed: 19500623]

[41]. Mann Steve, Nolan Jason, and Wellman Barry. 2002 Sousveillance: Inventing and using wearable computing devices for data collection in surveillance environments. Surveillance & society 1, 3 (2002), 331–355.

[42]. Marcu Gabriela, Dey Anind K, and Kiesler Sara. 2012 Parent-driven use of wearable cameras for autism support: a field study with families In Proceedings of the 2012 ACM Conference on Ubiquitous Computing. ACM, 401–410.

[43]. McMillan Donald, Brown Barry, Lampinen Airi, McGregor Moira, Hoggan Eve, and Pizza Stefania. 2017 Situating Wearables: Smartwatch Use in Context In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM, 3582–3594.

[44]. Megret Remi, Dovgalecs Vladislavs, Wannous Hazem, Karaman Svebor, Benois-Pineau Jenny, Khoury Elie El, Pinquier Julien, Joly Philippe, Andre-Obrecht Regine, Gaestel Yann, et al. 2010 The IMMED project: wearable video monitoring of people with age dementia In Proceedings of the 18th ACM international conference on Multimedia. ACM, 1299–1302.

[45]. Mok Tze Ming, Cornish Flora, and Tarr Jen. 2015 Too much information: visual research ethics in the age of wearable cameras. Integrative Psychological and Behavioral Science 49, 2 (2015), 309–322. [PubMed: 25537955]

[46]. Mukhopadhyay Subhas Chandra. 2015 Wearable sensors for human activity monitoring: A review. IEEE sensors journal 15, 3 (2015), 1321–1330.

[47]. Nebeker Camille, Lagare Tiffany, Takemoto Michelle, Lewars Brittany, Crist Katie, Bloss Cinnamon S., and Kerr Jacqueline. 2016 Engaging research participants to inform the ethical conduct of mobile imaging, pervasive sensing, and location tracking research. Translational Behavioral Medicine 6, 4 (2016), 577–586. 10.1007/s13142-016-0426-4 [PubMed: 27688250]

[48]. Neumann Peter G. 1994 Computer-related risks. Addison-Wesley Professional.

[49]. Ng Kher Hui, Shipp Victoria, Mortier Richard, Benford Steve, Flintham Martin, and Rodden Tom. 2015 Understanding food consumption lifecycles using wearable cameras. Personal and Ubiquitous Computing 19, 7 (2015), 1183–1195.

[50]. Nguyen David H, Bedford Aurora, Bretana Alexander Gerard, and Hayes Gillian R. 2011 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. ACM, 3207–3216.

[51]. Nguyen David H., Kobsa Alfred, Hayes Gillian R., Marcu Gabriela, Hayes Gillian R., Truong Khai N., Scott James, Langheinrich Marc, and Roduner Christof. 2008 Encountering SenseCam: Personal Recording Technologies in Everyday Life. UbiComp 8 2015 (2008), 182 10.1145/1620545.1620571

[52]. Nguyen David H, Marcu Gabriela, Hayes Gillian R, Truong Khai N, Scott James, Langheinrich Marc, and Roduner Christof. 2009 Encountering SenseCam: personal recording technologies in everyday life In Proceedings of the 11th international conference on Ubiquitous computing. ACM, 165–174.

[53]. Norman Don. 2013 The design of everyday things: Revised and expanded edition. Basic Books (AZ).

[54]. Phelan Chanda, Lampe Cliff, and Resnick Paul. 2016 It's Creepy, But it Doesn't Bother Me In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 5240–5251.

[55]. Pizza Stefania, Brown Barry, McMillan Donald, and Lampinen Airi. 2016 Smartwatch in vivo In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 5456–5469.

[56]. Price Blaine A., Stuart Avelie, Calikli Gul, Mccormick Ciaran, Mehta Vikram, Hutton Luke, Bandara Arosha K., Levine Mark, and Nuseibeh Bashar. 2017 Logging You, Logging Me: A Replicable Study of Privacy and Sharing Behaviour in Groups of Visual Lifeloggers. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol 1, 2, Article 22 (June 2017), 18 pages. 10.1145/3090087

[57]. Profita Halley, Albaghli Reem, Findlater Leah, Jaeger Paul, and Kane Shaun K. 2016 The AT effect: how disability affects the perceived social acceptability of head-mounted display use In

Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems. ACM, 4884–4895.

[58]. Profita Halley P, Clawson James, Gilliland Scott, Zeagler Clint, Starner Thad, Budd Jim, and Do Ellen Yi-Luen. 2013 Don't mind me touching my wrist: a case study of interacting with on-body technology in public In Proceedings of the 2013 International Symposium on Wearable Computers. ACM, 89–96.

[59]. Raij Andrew, Ghosh Animikh, Kumar Santosh, and Srivastava Mani. 2011 Privacy Risks Emerging from the Adoption of Innocuous Wearable Sensors in the Mobile Environment In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '11). ACM, New York, NY, USA, 11–20. 10.1145/1978942.1978945

[60]. Rapp Amon and Cena Federica. 2015 Affordances for self-tracking wearable devices In Proceedings of the 2015 ACM International Symposium on Wearable Computers. ACM, 141–142.

[61]. ResearchMatch. (accessed Dec 15, 2017).. https://www.researchmatch.org/

[62]. Risko Evan F and Kingstone Alan. 2011 Eyes wide shut: implied social presence, eye tracking and attention. Attention, Perception, & Psychophysics 73, 2 (2011), 291–296.

[63]. Saleheen Nazir, Ali Amin Ahsan, Hossain Syed Monowar, Sarker Hillol, Chatterjee Soujanya, Marlin Benjamin, Ertin Emre, Al'Absi Mustafa, and Kumar Santosh. 2015 puffMarker: a multi-sensor approach for pinpointing the timing of first lapse in smoking cessation In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing. ACM, 999–1010.

[64]. Unit sales of action cameras worldwide from 2010 to 2016. (accessed April 20, 2018).. https://www.statista.com/statistics/326898/worldwide-unit-sales-action-cams/

[65]. Shen Li and Stopher Peter R. 2014 Using SenseCam to pursue aAlJground truthaAi for global positioning system travel surveys. Transportation Research Part C: Emerging Technologies 42 (2014), 76–81.

[66]. Shinohara Kristen and Wobbrock Jacob. 2011 In the shadow of misperception: assistive technology use and social interactions In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems. ACM, 705–714.

[67]. Sridhar Srinath, Markussen Anders, Oulasvirta Antti, Theobalt Christian, and Boring Sebastian. 2017 WatchSense: On-and Above-Skin Input Sensing through a Wearable Depth Sensor In Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems. ACM, 3891–3902.

[68]. Stearns Lee, Oh Uran, Findlater Leah, and Froehlich Jon E. 2018 TouchCam: Realtime Recognition of Location-Specific On-Body Gestures to Support Users with Visual Impairments. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies 1,4(2018), 164.

[69]. Stunkard Albert J and Messick Samuel. 1985 The three-factor eating questionnaire to measure dietary restraint, disinhibition and hunger. Journal of psychosomatic research 29, 1 (1985), 71–83. [PubMed: 3981480]

[70]. Templeman Robert, Korayem Mohammed, Crandall David J, and Kapadia Apu. 2014 PlaceAvoider: Steering First-Person Cameras away from Sensitive Spaces.. In NDSS. 23–26.

[71]. Thomaz Edison, Essa Irfan, and Abowd Gregory D. 2015 A practical approach for recognizing eating moments with wrist-mounted inertial sensing In Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing. ACM, 1029–1040.

[72]. Thomaz Edison, Parnami Aman, Bidwell Jonathan, Essa Irfan, and Abowd Gregory D.. 2013 Technological approaches for addressing privacy concerns when recognizing eating behaviors with wearable cameras. Proceedings of the 2013 ACM international joint conference on Pervasive and ubiquitous computing - UbiComp '13 (2013), 739 10.1145/2493432.2493509

[73]. Troiano Richard P, McClain James J, Brychta Robert J, and Chen Kong Y. 2014 Evolution of accelerometer methods for physical activity research. BrJSports Med (2014), bjsports-2014.

[74]. Vaizman Yonatan, Ellis Katherine, Lanckriet Gert, and Weibel Nadir. 2018 Extrasensory app: Data collection in-the-wild with rich user interface to self-report behavior In Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems. ACM, 554.

[75]. van Rompay Thomas JL, Vonk Dorette J, and Fransen Marieke L. 2009 The eye of the camera: Effects of security cameras on prosocial behavior. Environment and Behavior 41, 1 (2009), 60–74.

[76]. Van Strien Tatjana, Frijters Jan ER, Bergers Gerard, and Defares Peter B. 1986 The Dutch Eating Behavior Questionnaire (DEBQ) for assessment of restrained, emotional, and external eating behavior. International Journal of Eating Disorders 5, 2 (1986), 295–315.

[77]. Wang Yang, Xia Huichuan, Yao Yaxing, and Huang Yun. 2016 Flying eyes and hidden controllers: A qualitative study of peopleaAZs privacy perceptions of civilian drones in the US. Proceedings on Privacy Enhancing Technologies 2016, 3 (2016), 172–190.

[78]. Wilson Gemma, Jones Derek, Schofield Patricia, and Martin Denis J. 2016 Experiences of using a wearable camera to record activity, participation and health-related behaviours: Qualitative reflections of using the Sensecam. Digital Health 2 (2016), 1–11. 10.1177/2055207616682628

[79]. Wolf Katrin, Schmidt Albrecht, Bexheti Agon, and Langheinrich Marc. 2014 Lifelogging: You're wearing a camera? IEEE Pervasive Computing 13, 3 (2014), 8–12.

[80]. Zhang Shibo, Alharbi Rawan, Nicholson Matthew, and Alshurafa Nabil. 2017 When Generalized Eating Detection Machine Learning Models Fail in the Field In Proceedings of the 2017 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2017 ACM International Symposium on Wearable Computers (UbiComp '17). ACM, New York, NY, USA, 613–622. 10.1145/3123024.3124409

CCS Concepts:

• **Human-centered computing** → **Ubiquitous and mobile computing theory, concepts and paradigms**; **Empirical studies in ubiquitous and mobile computing**; • **Security and privacy** → Social aspects of security and privacy;

Fig. 1.

Researchers have studied the effect of ego-centric cameras (first-person view with the lens pointing outward) on wearers and bystanders or have studied the effects of surveillance cameras (third-person view). We extend these efforts to study what we call activity-oriented cameras (such as [55, 68] and the three cameras used in this study) - cameras designed to record a specific activity rather than the gaze or the view of the participant, like the ego-centric camera [27, 28, 65], nor the total scene, like the surveillance camera [2, 50, 77].

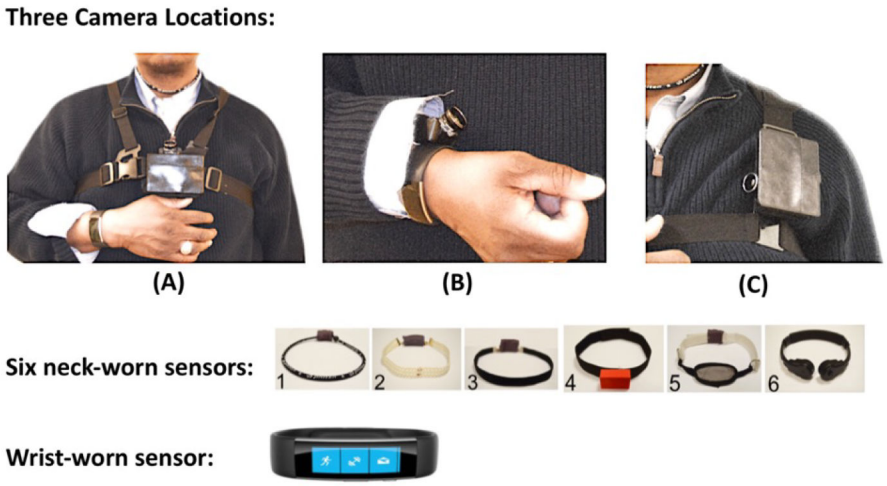

Fig. 2.

Wearables used in this study. Three camera designs: (A) Chest camera, (B) Wrist camera, and (C) Shoulder camera. Six neck-worn devices for participants to choose one from. Wrist-worn sensor (mBand2).

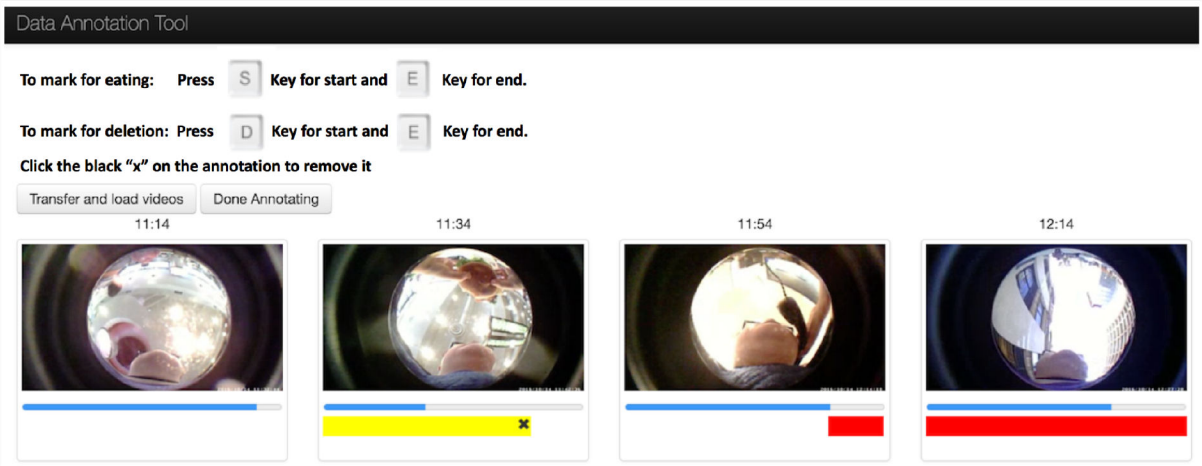

Fig. 3.

Video reviewing software that allows the participants to view the videos collected, delete segments (shown in red) or mark the start and end of an activity (shown in yellow).

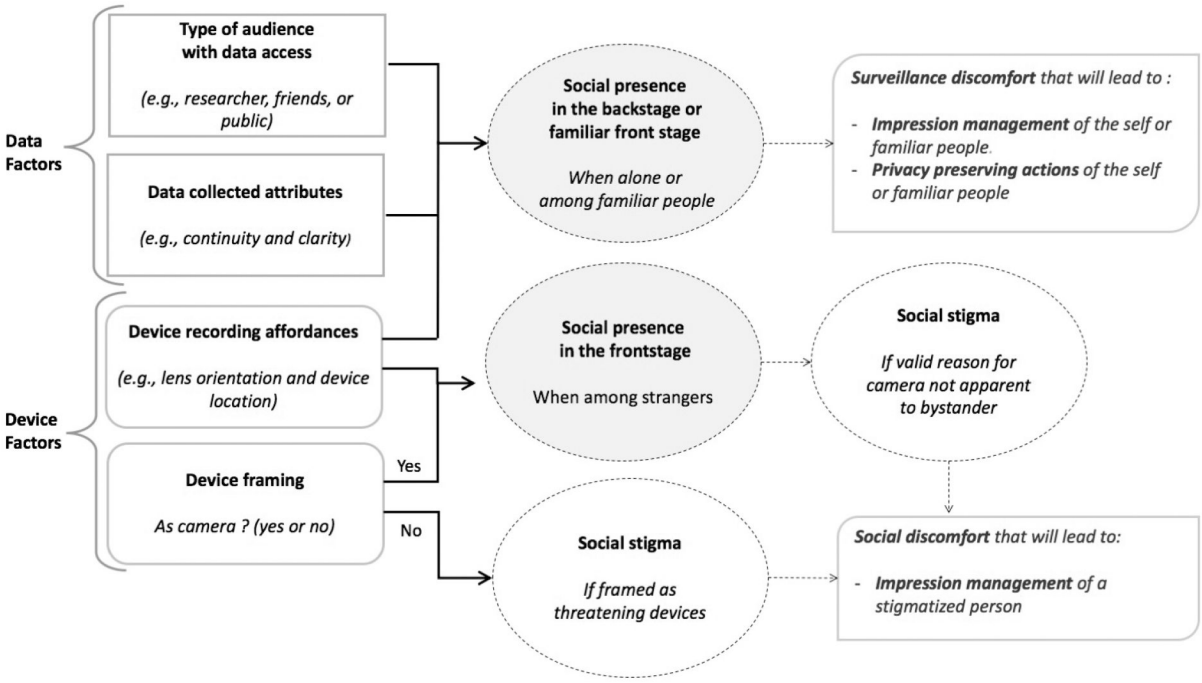

Fig. 4.

Our proposed model explains the factors that influence perceived social presence and stigma. When the camera is worn while alone or among familiar people, privacy-preserving techniques applied on data-related factors (such as restricting data attributes and limiting the type of people who have access to data) can decrease social presence both in ego-centric and activity-oriented cameras (if these settings are known by the wearer and bystanders). However, when among strangers, communication of privacy-preserving techniques on data factors is not feasible. Therefore, only device recording affordances based on visible characteristics can affect social presence among strangers. Unlike the ego-centric camera, activity-oriented cameras can reduce social presence among strangers via device recording affordances. Changes to device recording affordances and framing - especially ensuring that a device is not perceived as threatening - in turn, reduce social stigma.

Table 1.

Experiment procedure describing the steps performed by each participant in order.

Section	Step	Description
3.3.1	Informed Consent	Researcher explained the study to participants and answered participants' questions about the study and a set of pre-questionnaires were administered: Eating habit questionnaire (emotional[76], hedonic[69], binge[24], impulsive[40]). Social media usage and privacy expectation [See supplement material]. Privacy Attitude [8].
3.3.2	Wearable Devices	One camera design assigned to participant (chest, shoulder or wrist). Participants selected a neck-worn sensor design of their choice. Participant wore the smartwatch.
3.3.3	Structured Activities	Participants were asked to perform the following activities while wearing the devices assigned to them: • Walk on Michigan Avenue and ask a stranger for directions. • Eat at home or in a restaurant. • Go to a coffee shop and order water or a drink. • Use a bathroom. • Check email. • Use an ATM.
3.3.3	Unstructured Activities	Participants were instructed to continue wearing the devices for at least two additional hours while performing any activity of their choice. (See Table 3 for list of activities performed by participants)
3.3.4	Post-Experiment Questionnaire	Participants were asked to answer open-ended questions about their experiences while wearing the device in the wild. [See supplement material]
3.3.5	Other Cameras	Participants were asked to don the two remaining camera designs. They were asked to engage in structured activity that included going to the supermarket, using a computer, eating a snack and looking at themselves in the mirror. After wearing each camera design they were asked open-ended questions about the camera.
3.3.6	Video Review	Participants were asked to look at the videos they captured with each wearable camera and to delete any segments that they did not want to share with the research team. They were administered another set of questions after viewing the video to test whether the perceived burden of wearing the camera changed after viewing the video. [See supplement material]
3.3.7	Interview	Semi-structured interview to probe the participants about answers they provided in the post-experiment questionnaire.

Table 2.

Participant demographics, employment, and camera assigned in the wild.

	Gender	BMI	Age	Ethnicity	Employment	Camera assigned (in wild)
P1	F	Overweight	22	Asian	Full time employed	Chest
P2	F	Overweight	22	Hispanic	Full time employed	Shoulder
P3	F	Normal	24	White	Full time employed	Wrist
P4	M	Overweight	26	Asian	Not employed	Chest
P5	M	Obese	30	Asian	Student	Chest
P6	F	Obese	58	White	Not employed	Chest
P7	M	Normal	31	Hispanic	Not employed	Wrist
P8	M	Normal	24	Asian	Full time employed	Shoulder
P9	F	Obese	43	-	Full time employed	Shoulder
P10	F	Obese	62	White	Part time employed	Wrist
P11	F	Obese	31	White	Full time employed	Shoulder
P12	F	Obese	35	White	Full time employed	Chest
P13	F	Normal	22	Asian	Student	Chest
P14	M	Overweight	29	White	Full time employed	Wrist
P15	F	Obese	43	Asian	Student	Wrist
P16	F	Normal	27	Black	Not employed	Shoulder
P17	M	Obese	58	Black	Not employed	Wrist
P18	F	Obese	46	Black	Not employed	Chest
P19	M	Obese	53	Black	Retired	Wrist
P20	F	Normal	19	Black	Student	Wrist
P21	M	Obese	31	White	Full time employed	Shoulder
P22	M	Obese	52	Black	Full time employed	Shoulder
P23	M	Overweight	27	White	Full time employed	Shoulder
P24	M	Normal	23	White	Student	Chest

Table 3.

Unstructured Activities

	Unstructured Activity	Location
P1	Worked on a computer, phone calls with clients, chatted with coworkers, ate a snack, walked	Work - Volunteering event
P2	Worked on a computer, phone calls with clients, chatted with coworkers, ate a snack	Work
P3	Worked on a computer, chatted with coworkers	Work
P4	Worked on a computer	Home
P5	Worked on a computer, chatted with coworkers	Work
P6	Sat on a bench, talked to people and on the phone	Park
P7	Worked on a computer	Library
P8	Shopped, attended a lecture	Clothing store - Work
P9	Worked on a computer and had an online meeting	Car
P10	Reading a book, chatted	Coffee shop
P11	Worked on a computer, chatted with coworkers	Work
P12	Had a phone call, shopped	Clothing store
P13	Worked on her computer, used her phone	Coffee shop
P14	Shopped, walked outside, sat in a waiting area	Mall - Park - Bus
P15	Shopped, worked on her laptop	Cosmetic store - Coffee shop
P16	Drank coffee, smoked	Coffee shop
P17	Shopped, walked	Clothing store - Park
P18	Walked	Park
P19	Shopped and sat	Jewelry store - Coffee shop - Bus
P20	Shopped and talked on the phone	Mall - Food court
P21	Shopped with a friend	Mall
P22	Talked to people and sat	Bus - Home
P23	Watched TV, cleaned his house, worked on computer	Home - Bus
P24	Sang a song at home, went to class, talked with friends in school	Home - School

Table 4.

Themes and codes emerged from coding responses to open-ended questions and interview content. The last column shows the number of participants (n).

Theme	Description	Code	n
Device discomfort	Discomfort that is related to the device itself. Surveillance and social discomfort are not coded here	Physical	12
		Constraints	7
		Attachment	6
Surveillance discomfort	Discomfort that is related to surveillance and recording. It can be about the self or others	Surveillance of the self	11
		Surveillance among familiar people	5
		Surveillance among strangers	7
Video factors	Video or recording factors that emerge when talking about comfort or discomfort	Recording clarity	8
		Recording scope	9
		Recording continuity	2
Bystanders reactions	Participants reported bystander reaction. It is about a specific interaction that a participant mentions rather than a general one	Looks	7
		Little or no reaction	5
		Implied negative comments	2
		Discomfort	3
Bystanders questions asked	Questions that the bystander asks after the participant explains to them that they are participating in a research study	Curiosity or interest	7
		Privacy concerns	1
		Device functionality	2
Social discomfort	Any discomfort that emerges in a social context around people. It can be an anticipated discomfort mentioned by the participant or an actual one	Similar to threatening device	4
		Fear/burden of explanation	8
		Aesthetic appearance of the device	3
Normality factors	Factors affecting where it felt “normal” to wear the device	Other/general	17
		Similar to common devices	11
		Device location	12
		Context	12
		Device visual noticeability	16
		Shape or size	18
		Lens direction	10
Device design factors	Device design factors that emerge when talking about comfort or discomfort	Controllable	4
		Attachment style	12
		Color	1
		Functionality suggestions	1
		Concealment suggestions	7
Resolve discomfort	Any action that the participant takes because of a discomfort caused by the camera	Modification to authentic behavior	10

Theme	Description	Code	n
		Manipulation of environment	1
		Concealing or removing the device	14