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Using Wearable Cameras to Investigate Health-Related Daily Life Experiences: A Literature Review of Precautions and Risks in Empirical Studies

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Abstract

Automated, wearable cameras can benefit health-related research by capturing accurate and objective information about individuals' daily experiences. However, wearable cameras present unique privacy- and confidentiality-related risks due to the possibility of the images capturing identifying or sensitive information from participants and third parties. Although best practice guidelines for ethical research with wearable cameras have been published, limited information exists on the risks of studies using wearable cameras. The aim of this literature review was to survey risks related to using wearable cameras, and precautions taken to reduce those risks, as reported in empirical research. Forty-five publications, comprising 36 independent studies, were reviewed, and findings revealed that participants' primary concerns with using wearable cameras included physical inconvenience and discomfort in certain situations (e.g., public settings). None of the studies reviewed reported any serious adverse events. Although it is possible that reported findings do not include all risks experienced by participants in research with wearable cameras, our findings suggest a low level of risk to participants. However, it is important that investigators adopt recommended precautions, which can promote autonomy and reduce risks, including participant discomfort.

Keywords

Wearable camera; wearable electronic device; research ethics; health behavior; review

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Declaration of Conflicting Interests

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Introduction

Automated, wearable cameras (henceforth, “wearable cameras”) can be used to obtain more objective information about daily life experiences. Wearable cameras are programmed to take still photos automatically (i.e., without prompting by the wearer) at set intervals (e.g., every 2–20 seconds). These cameras are typically worn in the upper chest region (e.g., pinned to the shirt) (Wilson, 2017) and use a wide-angle lens designed to capture as much of the wearer’s environment as possible. To maximize storage capacity, their photos are relatively low-resolution (Hodges et al., 2012). Examples of wearable cameras include the Microsoft SenseCam, one of the first to become popular among investigators (Doherty et al., 2013), and the eButton, a more recent device designed specifically for research rather than commercial use (Sun et al., 2014). Studies across a range of fields (e.g., public health, psychology, human-computer interaction) have employed wearable cameras to supplement or replace traditional data collection methods (e.g., self-report) (e.g., Chambers et al., 2018; Gemming et al., 2015b; Gouveia & Karapanos, 2013; Kerr et al., 2013; O’Loughlin et al., 2013).

Wearable Cameras in Health-Related Research

Investigations of daily life experiences can provide important information relevant to health (Doherty et al., 2013). For one, daily life experiences include health-related behaviors (e.g., eating, physical activity) and health-related exposures (e.g., alcohol advertising). Also, recording daily life experiences makes it possible to investigate memory of those experiences, which can be impaired in certain conditions or diseases.

Research into daily experiences typically relies on self-report methods; however, self-report of behavior can be inaccurate for various reasons. Inaccuracies may result from typical limitations of memory and attention (e.g., forgetfulness, greater attention to certain events) (Evers et al., 2009; Hodges et al., 2006; Kelly et al., 2011) or impairments of memory and attention (e.g., dementia) (Hodges et al., 2006). Participants may also misreport behaviors, particularly those that are commonly viewed as socially desirable or undesirable. For example, in research on dietary behavior, most individuals tend to underreport their actual food intake (Dhurandhar et al., 2015; Novotny et al., 2003; Poslusna et al., 2009), which could reflect memory limitations, subconscious biases in reporting, conscious misreporting, or a combination.

The use of wearable cameras offers benefits for assessing daily experiences when those experiences can be observed visually and when self-report has significant limitations. For example, in the area of dietary assessment, recent research suggests that using wearable cameras to supplement self-reported food intake reduces dietary under-reporting (Gemming et al., 2013; O’Loughlin et al., 2013). Wearable cameras have also been used to assess other health-related behaviors (e.g., sedentary behavior (Doherty et al., 2013) or physical activity (Taylor et al., 2015)), as well as health-related exposures (Barr et al., 2015; Cowburn et al., 2016). Additionally, wearable cameras have emerged as a method for investigating autobiographical memory in healthy individuals and especially in individuals with memory impairments (Allé et al., 2017). In contrast to more standard methods of experience recording (e.g., participant-initiated photographs), use of wearable cameras presents fewer

challenges for individuals with memory impairments (Dubourg et al., 2016) and may be less likely to alter the memory processes under investigation (Allé et al., 2017).

Risks of Wearable Cameras

The same aspects of wearable cameras that make them valuable as a tool for health-related research can also potentially increase risks to participants. Wearable cameras pose risks standard to all wearable technology, including physical discomfort (Cowburn et al., 2016) and noticeability of the technology (Kwok et al., 2015; Nebeker et al., 2016), as well as concerns about confidentiality of data during collection, transfer, and storage (Mok et al., 2015; Nebeker et al., 2017). However, the nature of the information captured in images increases some of those risks (e.g., confidentiality). Additionally, because wearable cameras capture not only the experiences being investigated but all events appearing in the photo frame, the resulting images may contain identifying or sensitive information. This introduces two types of privacy-related risks (Kelly et al., 2013).

Participant Privacy—The possibility of capturing identifying or sensitive information, especially unintentionally, presents risks to the privacy of participants (Kelly et al., 2013). Photos may capture bank account details appearing on a screen, nudity, or other sensitive, embarrassing, or illegal activities, such as child abuse or drug use, and participants may experience discomfort with private details of their life being shared. More rarely, participants could experience psychosocial and/or legal consequences based on information contained in the images (e.g., due to mandated reporting of child abuse).

Bystander Privacy—Because of the potential for capturing information from third parties (e.g., bystanders in the participant's environment), participants in studies with wearable cameras also face risks related to bystander privacy (Kelly et al., 2013; Kwok et al., 2015). Participants may experience anxiety about bystanders' reactions to the camera, may feel distressed if bystanders have negative reactions, or, more rarely, may suffer legal consequences related to bystander privacy (Brown et al., 2017; Kelly et al., 2013). For instance, photographing third parties without consent in certain situations (e.g., locker rooms) could result in criminal charges (e.g., due to violating laws designed to protect individuals against being photographed without their consent when not fully clothed).

Ethical Use of Wearable Cameras

To help protect participants from these risks, a group of experienced investigators have developed guidelines for the ethical use of wearable cameras in behavioral research. These guidelines are consistent with the principles used by institutional review boards (IRBs) (Kelly et al., 2013), aligning with the Belmont Report (National Commission for the Protection of Human Subjects of Biomedical and Behavioral Research, 1979), with attention also paid to bystanders' rights. The recommended practices address the following: 1) informed consent of the participant (e.g., consent process should explain that participants may forget they are wearing the camera and thus capture unwanted photos); 2) privacy and confidentiality (e.g., participants should be permitted to remove the camera at any time, camera should be configured so that images can only be retrieved by research team); 3) non-maleficence (e.g., participants should be told to remove the camera if they receive

unwanted or negative reactions); and 4) third-party autonomy (e.g., participants should obtain verbal permission from cohabitants before beginning the study).

In addition, other experienced investigators have established principles for preserving privacy when collecting, analyzing, and storing images collected during research involving wearable cameras (Skatova et al., 2015). These principles, which have been implemented in a smartphone app developed by the investigators, include storing and analyzing images locally (e.g., on participants' phones), only sending the investigator anonymized images that are relevant to the research question, and encrypting images during all storage and transfer processes.

Current Review

Despite the existence of these guidelines and principles, information on the actual risks and benefits of studies employing wearable cameras remains limited, which poses a barrier for investigators and IRBs considering how to evaluate and mitigate potential harm. Without data on the precautions and risks common in research with wearable cameras, investigators face challenges in designing their studies to minimize camera-related risks. Similarly, IRBs struggle to conduct risk assessments of these protocols, which may lead to delays and additional burden on investigators to explain and anticipate potential risks (Nebeker et al., 2017). To better guide investigators' and IRBs' decisions, a comprehensive review of findings regarding camera-related risks (e.g., adverse events) and the precautions taken to reduce those risks is needed. Most existing reviews of wearable camera research have focused on specific areas of health research, such as memory (Allé et al., 2017; Chow and Rissman, 2017; Dubourg et al., 2016; Silva et al., 2018) or physical activity (Loveday et al., 2015). Only one review has examined ethical issues concerning the use of wearable cameras, aggregating literature across several fields, including market research (Mok et al., 2015). However, no existing reviews have comprehensively examined the precautions and risks relevant to using wearable cameras in studies investigating daily experiences.

Thus, we conducted a literature review of empirical studies that included wearable cameras, with the aim of surveying available empirical data on: 1) the types of precautions investigators report employing to mitigate the risks to participants of using wearable cameras; and 2) findings relevant to camera-related risks, including participants' acceptability of and experiences with using wearable cameras, as well as adverse events related to using the wearable cameras.

Methods

We performed a literature review to identify studies that included the use of automated wearable cameras to investigate human daily experiences. The search protocol was modified from the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (Moher et al., 2009). Development of our search, screening, and data extraction procedures occurred in two phases. In April 2018, we performed an initial search of two databases (PubMed and PsycINFO) using the following search terms and strategy: eButton wearable camera OR SenseCam OR Vicon Revue OR Autographer OR GoPro OR "wearable camera." At that time, we developed eligibility and data extraction procedures (described

below). The initial search did not capture all relevant papers of which the authors were aware. Thus, in November 2019, we performed a second, more extensive search using expanded search terms and an additional database, in order to conduct the current review. Specifically, three databases were searched (PubMed, PsycINFO, and EMBASE) using the following search terms and strategy: eButton OR SenseCam OR Vicon Revue OR Autographer OR GoPro OR (camera AND phone) OR (camera AND wear*). Searches were limited to publications that were published before April 1, 2018 (the date we initiated the initial search), written in English, and included human participants. Of note, we did not filter for articles with a particular focus (e.g., health-related behaviors), since articles across broad areas of investigation would provide relevant information on camera-related precautions and risks, and our goal was to identify the most comprehensive set of relevant articles. However, our selection of databases – specifically, databases that are commonly searched when conducting health-related reviews – was informed by our backgrounds in health-related research. As a result, almost all relevant articles from our search pertained to health. All references identified in the second search were imported into Covidence, an online, systematic review management software. The second search resulted in a total of 1,325 articles, which were screened for eligibility in two phases, described below. Please also refer to Figure 1 for a flowchart of the search and screening process.

First, two authors (LP and KNJ) screened the titles and abstracts to identify potentially eligible articles. Articles were deemed eligible if they met all of the following eligibility criteria: 1) text in English; 2) published online or in print before 04/01/2018; 3) presents findings of original, empirical research (i.e., not a theoretical manuscript or review of studies reported elsewhere); 4) includes human participants; 5) participants wore a camera that took photos automatically; 6) camera worn as part of the study protocol (i.e., not as part of life logging activities engaged in by the participant prior to and independent of the study); 7) camera worn to document daily experiences that are not specific to a profession (e.g., studies using wearable cameras to document surgical procedures, or studies of police body cams, were excluded); 8) camera worn in participants' own everyday environment (i.e., not only in the laboratory, or during prescribed activities such as an outing with the investigator); 9) camera worn in locations where participant could reasonably encounter bystanders who are non-cohabitants and not participating in or aware of the study; 10) wearable camera system did not capture video and/or audio. We established criteria 7–9 to eliminate studies in which wearable cameras were used but did not pose the full range of camera-related risks relevant to this review, such as participants receiving negative reactions from bystanders. Conversely, criterion 10 eliminated studies that posed risks beyond those associated with the use of wearable cameras to capture still photos, due to the capture of audio or video. Additionally, publications were excluded if they were 11a) case studies or 11b) conference proceedings that included only an abstract, since these were unlikely to include information sufficient for analyses. A total of 100 duplicate articles were removed; eighty-five duplicates were identified automatically by Covidence, and 15 duplicates were identified manually by the second and last authors. These authors marked "no," "maybe," or "yes" to indicate each article's eligibility status based on the article's title and abstract. All articles with conflicting decisions were flagged by Covidence, and the last author and second author reviewed each abstract together to reach a consensus.

Next, two authors (LP and CJ) scanned the full text of the 103 articles identified as potentially eligible (i.e., marked as “yes” or “maybe”). This resulted in the exclusion of 62 articles for the following reasons, numbered according to the corresponding eligibility criteria (see above): 3) not original, empirical research (12 articles); 5) camera not worn or picture taking not automatic (11 articles); 6) camera not worn as part of the study protocol (2 articles); 7) camera not worn to document common daily experiences (2 articles); 8) camera not worn in everyday environment (8 articles); 9) camera not worn around true bystanders (1 article); 10) camera took video and/or audio (9 articles); 11a) case study(ies) (3 articles); 11b) conference proceedings (14 articles). Eligibility criteria were ordered starting from general to specific, and reviewers selected the first reason in the list that a given article was not eligible; thus, articles could have been excluded for more than one reason. Forty-one papers from the full-text review met all eligibility criteria. Additionally, the authors identified four additional, potentially relevant articles from the results of the initial search. These articles were subjected to the same screening processes described above, resulting in a total of 45 eligible articles.

Review of these articles suggested that, in some instances, multiple articles referred to the same sample of participants (i.e., data came from the same study). In total, the 45 articles were based on 36 independent studies. As described below, data were extracted for each study, using all relevant articles, rather than for each article. This ensured that we did not incorrectly portray a precaution or risk as occurring multiple times (i.e., if it was reported in two or more articles referring to the same study).

The last stage of the literature review included analyzing the main manuscript and supplemental materials for all 45 eligible articles. We also analyzed any articles that an article cited as providing further information on its study procedures (e.g., Signal et al. (2017) provides additional details on the study presented in Chambers et al. (2017, 2018)). To survey the precautions and findings relevant to camera-related risks, we extracted the following information from all articles pertaining to each independent study: (a) description of the study aims, with a focus on aims relevant to use of wearable cameras; (b) description of the sample, including participant number, demographics, and brief description of eligibility criteria with a focus on criteria relevant to camera-related risks; (c) brief description of procedures, with a focus on camera-related procedures; (d) description of reported camera-related precautions; (e) description of any findings relevant to camera-related risks, including participants’ acceptability of and experiences with using wearable cameras and any adverse events related to use of wearable cameras. Regarding acceptability, we focused primarily on the acceptability of *wearing* cameras to document daily experiences, rather than on the acceptability of viewing the resulting images (e.g., to reflect on past experiences), since the latter tends to be a common feature of only certain types of studies (e.g., those investigating autobiographical memory).

Results

This results section does not contain in-text citations; for the same results section with in-text citations for the relevant studies, see Supplemental Material (Results Section with

Citations). For Table 1, which summarizes the results for all eligible studies and includes a full references list, see Supplemental Material (Table 1).

Almost all of the 45 eligible articles pertained to health-related topics, namely health-related behaviors, health-related exposures, and autobiographical memory. Only two studies did not have a health-related focus (see Table 1 footnotes). Of the 36 independent studies, nine included child or adolescent participants, seven included older adults, and the remaining studies included primarily young and middle-aged adults. Most studies did not focus on patient groups, with many samples including only "healthy" individuals. However, three studies focused on older adults with mild Alzheimer's Disease, one study included older adults with severe aphasia, and another study included older adults who had recently fallen.

Camera-Related Precautions

Studies reported a wide range of camera-related precautions, ranging from no precautions in six studies (17%) to precautions fully consistent with the best practice guidelines in a study conducted by the guidelines' authors.

Precautions Related to Participant Privacy and Confidentiality—The most common precautions concerned participant privacy and confidentiality. In 50% of studies, investigators reported informing participants that they could remove or temporarily disable the device at any time or in certain situations, such as situations where the participant felt uncomfortable or where privacy would be expected (e.g., bathroom). Thirty-six percent of studies instructed participants in using a "privacy button" to temporarily disable the device for a short period (4–7 minutes). In one study, participants' (with severe aphasia) communication partners were shown the location of the privacy button, but no other instruction was given. The least common precaution with regard to removing or disabling the camera was instructing participants to turn on the camera only before relevant events, with only one study reporting this precaution. Close to half of the studies (44%) allowed participants to delete photos they did not wish to share with study staff, either by having participants review the photos, noting a time period for deletion by study staff, or both. Precautions regarding proper data security were less consistent, with at least one reported in 36% of studies. Commonly-reported precautions regarding proper data security, from most to least common, included: ensuring that photos stored on the phone were encrypted and/or accessible only to study staff; ensuring that photos were subsequently stored in a location that was secure and/or accessible only to study staff; requiring study staff to complete additional training and/or sign confidentiality/data release agreements; or deleting photos not relevant to the scientific question.

Precautions Related to Bystander Privacy—With regard to capturing information from bystanders, the most common precaution was instructing participants to remove or temporarily disable their devices in certain situations (50% of studies), as noted above. Also, in four studies (11%) with children, researchers reported obtaining permission to conduct the study from the participants' school(s). Only two studies (6%) required participants to obtain permission to record at home and/or work prior to wearing the camera. In three studies (8%), investigators reported encouraging participants to ask permission to use the camera in

certain settings (e.g., a private meeting). Finally, four studies (11%) instructed participants in handling questions or reactions from bystanders, which in three of these included providing participants with study information cards to give to bystanders.

Additional Findings Relevant to Camera-Related Precautions—Notably, across four studies (11%), investigators reported practices inconsistent with recommended precautions, such as allowing participants to view the camera images on their own during the camera-wearing week and discouraging participants from turning off or disabling the camera.

In one study (conducted by authors of the aforementioned best practice guidelines), a subset of participants provided feedback on the appropriateness of those precautions at study end. Regarding informed consent, 95% reported that the consent form accurately described their experiences during the study, and approximately one quarter suggested including additional information, such as an example image.

Camera-Related Risks

General Experiences—No studies reported serious adverse events related to the use of wearable cameras.

Thirty-one percent of studies reported findings related to general acceptability. Across three studies (8%), participants generally found the camera protocol acceptable and were happy to wear the camera. In another four studies (11%), most participants felt comfortable wearing the cameras or with the research overall. In five studies (14%), participants found the cameras to be a low burden overall or expressed few general concerns related to wearing them. One notable exception was a study in which participants wore a cellphone containing the automated camera around their necks, with 71% of participants reporting that wearing the camera all day was ‘somewhat’ to ‘very difficult’.

Several studies assessed participants’ specific camera-related concerns. One of the most commonly reported concerns was physical inconvenience (i.e., camera’s excessive movement, interference during physical activity, weightiness). Although findings regarding physical inconvenience were only reported in three studies (8%), physical inconvenience was the most endorsed concern among those participants. Additionally, in the study that involved wearing a cellphone, several participants reported that it was cumbersome and stated they would have preferred a smaller, less noticeable camera. A second, common participant concern, reported across four studies (11%), was feeling uncomfortable wearing the camera in certain situations, particularly in locations with bystanders (e.g., others’ homes or public places). In two of those studies, about one-third of participants reported discomfort with wearing the camera in certain situations, typically in public (e.g., riding the bus). Likewise, in the third study, adolescent participants reported being uncomfortable wearing the camera in certain situations (e.g., at a friend’s house). However, another adolescent study reported that general camera-related concerns decreased as participants adjusted to wearing the camera. Additional concerns related to the camera’s fashionability and physical operation (reported by child participants). In one study, one adult participant reported not

enjoying wearing the camera because of the belief that it drew attention to them and their disability, and created feelings of embarrassment.

Experiences Related to Participant Privacy—No studies reported serious adverse events related to participant privacy. When asked, participants generally had few concerns about privacy related to the use of wearable cameras, and they reported that concerns and awareness of the camera diminished with time (reported across 8% of studies). One study of children and their parents reported that, of 33 initially consented participants, less than 9% were removed from the study due to confidentiality or privacy related concerns or lack of compliance. In a study of eating behavior where participants knew they would be subsequently reviewing their images with a nutritionist, half of the participants noted that they were conscious of the camera while eating. Additionally, in one adolescent study, approximately two-thirds of non-participants cited wearable cameras as a reason for non-participation, with over one-third noting their own (or parental) concerns about their privacy; however, non-participants expressed greater concern about wearing a GPS device.

Findings related to disabling, covering, or removing the camera to protect participants' (or others') privacy were reported by 19% of studies. Among these studies, the frequency of this practice varied. Two studies with adults reported that most participants chose not to record during certain situations (e.g., when using the restroom or during personal hygiene), and a third adult study reported that participants used the privacy button at least 20% of the time the camera was on. In one study of children and their parents, the majority of participants removed or disabled the camera at least once a day for privacy-related reasons. In contrast, two other adult studies reported minimal instances of removing or disabling the camera or only a single instance of using the privacy button, although participants in the latter study notably identified the privacy button as a key factor in their willingness to participate. In one study where multiple family members wore cameras simultaneously and subsequently viewed the resulting images, participants reported turning off their cameras to avoid capturing images that might misrepresent their everyday lives to family members.

Five studies (14%) reported statistics related to the review and deletion of images by study participants or study staff to protect participants' (or others') privacy. The number of participants electing to review the images ranged from just a few to almost all participants. In one of these studies, the proportion of participants who chose to review images decreased by about 50% between the first and third study visits. In another of these studies, only about one third of participants who reviewed images chose to delete any. Participants who did so typically deleted only a few images and at most 1% of images. In another study, investigators intended to exclude photos capturing events of high personal significance from use in a subsequent neuroimaging task, but no such events were captured.

Experiences Related to Bystander Privacy—No studies reported serious adverse events related to bystander privacy (e.g., legal consequences), complaints from bystanders, or requests that the participant surrender the camera.

Six studies (17%) reported findings related to the amount of attention participants received from bystanders and/or participants' reactions to such attention. In three studies, 50% to

100% of participants reported receiving attention from or being approached by bystanders, with almost half the participants in one of these studies asked about the camera five or more times. Participants in a fourth study rated bystander awareness and attention as a 3, on average, on a scale from 1 (not at all) to 5 (a great deal). In contrast, one study reported that participants received little attention from bystanders. As noted above, several studies reported that some participants experienced discomfort or concern about attracting negative attention in public places. Generally, most participants found that the actual attention was non-problematic and decreased over time. However, in one child study, one quarter of participants found the attention uncomfortable, and 8.3% of parents were concerned about it.

Four studies (11%) provided participants with bystander cards or a prepared response, and few or no participants reported using the cards or responses. Participants in one of these studies reported that they preferred verbal explanation to the cards, although participants in another study indicated that they appreciated having the cards despite not handing any out. Participants in the latter study noted that most bystanders were unconcerned after learning about the camera's purpose. Likewise, in one study where bystander cards were provided, no bystanders contacted the investigator.

As noted above, participants reported disabling or removing the camera proactively in certain situations to protect others' (or their own) privacy. In 11% of studies, participants reported removing the camera where it was polite (e.g., at school gates waiting for children), where photography was prohibited (e.g., airports), or where it might make others feel uncomfortable (e.g., friend's house). Additionally, 8% of studies reported that participants turned off or removed the camera in response to bystander requests, with two noting that between one-tenth and one-fifth of participants reported receiving these requests.

Discussion

Wearable cameras have been used in health-related research for over a decade, including in investigations of health-related behaviors, health-related exposures, and autobiographical memory (Chambers et al., 2018; Doherty et al., 2013; Finley et al., 2011). In these areas of investigation, standard methods of assessment (e.g., self-report, or observer report) have substantial limitations (Dhurandhar et al., 2015), and wearable cameras have, by comparison, great potential to provide more objective information with less reactivity to assessment, especially once the participant has acclimatized to the camera. However, the features that make wearable cameras so useful (i.e., their automaticity, creation of photographic records of daily experiences) also means that these cameras capture extraneous information not relevant to the scientific question. This information can include identifying and sensitive information from participants or from third parties, such as bystanders. Thus, in keeping with best practices for ethical research with wearable cameras (Kelly et al., 2013), investigators should employ precautions to protect the privacy and confidentiality of participants and third parties, and to protect participants from adverse reactions from bystanders. The current review is the first to summarize the risks of using wearable cameras, and the types of precautions taken to mitigate those risks, reported in empirical research.

To survey reported camera-related precautions and risks, we reviewed 45 empirical articles that were published by March 2018 and used wearable cameras to examine daily experiences. These articles, which predominantly focused on health-related topics, included 1,398 participants in total from 36 independent studies of children, adolescents, and adults, including older adults. Although most participants were healthy, some studies included individuals with physical health concerns (Taylor et al., 2015) or neuropsychiatric illness or impairment (Silva et al., 2017).

The reviewed studies reported a range of camera-related precautions, ranging from no reported precautions (e.g., Cuberos-Urbano et al., 2018) to precautions fully consistent with best practices (Nebeker et al., 2016). The most common precaution was instruction to disable or remove the camera during private moments or in certain situations (e.g., bathrooms) (e.g., Finley et al., 2011). Other common precautions included allowing participants to review and delete images (e.g., Gemming et al., 2015a) and data security precautions (e.g., Robinson et al., 2017).

No studies reported serious adverse events related to the use of wearable cameras, including events related to participant or third-party privacy (e.g., serious participant distress, legal consequences, hostile bystander reactions). Participants generally found cameras to be acceptable with a low burden of inconvenience, excepting one study involving a cellphone worn around the neck (Arab et al., 2011). In studies that assessed participants' specific camera-related concerns, the most commonly reported concerns were related to physical inconvenience (e.g., Kelly et al., 2015) and discomfort with wearing the camera in certain situations (e.g., Kelly et al., 2012). Participants generally reported few privacy-related concerns, and some reported that concerns diminished with time (e.g., Cowburn et al., 2016). The minimal concern with privacy is not surprising given that participants volunteered for a study with wearable cameras, and that participants reported using the option of disabling or removing the camera to protect their own (or others') privacy (e.g., Brown et al., 2017), although reports on the frequency of this practice varied. When given the option to review and delete images, some to almost all participants elected to do so (e.g., Nebeker et al., 2016), but only a minority of participants tended to delete images, typically a very small number (e.g., Robinson et al., 2017).

Regarding bystander reactions, some participants cited discomfort or concern about attracting negative attention in public places when wearing the camera (e.g., Gemming et al., 2013). These concerns tended to be heightened for less subtle cameras (Arab et al., 2011) and in studies with small children (Beltran et al., 2016), in that they might be approached by strangers because of the camera. In studies where participants reported that the camera received attention from bystanders, the attention was generally found to be non-problematic (e.g., Signal et al., 2017), except by a minority of participants and their parents in a study of small children (Beltran et al., 2016; Raber et al., 2018). No studies reported complaints from bystanders, and in studies that provided participants with bystander cards, few participants reported handing out cards, although some did describe the cards as helpful (Barr et al., 2015). Several studies reported that bystanders with concerns were satisfied with verbal explanation or removal of the camera (e.g., Nebeker et al., 2016), and no studies reported hostile reactions from bystanders or requests to surrender the camera.

Given these findings, we present some recommendations regarding the use of wearable cameras in research:

1. Investigators should familiarize themselves with recommendations for ethical research with wearable cameras (Kelly et al., 2013; Skatova et al., 2015) and should adopt recommended precautions, which can promote autonomy and reduce risks, including participant discomfort (e.g., in public settings). We would generally recommend adopting all recommended precautions (Kelly et al., 2013), although additional precautions may be required by the investigator's IRB (or the institution's legal counsel) or dictated by the research setting (e.g., asking permission of schools for child participants). Further, investigators should report all camera-related precautions in the Methods section of publications, or in supplemental materials if necessary.
2. Before conducting scientific investigations with wearable cameras, investigators should first conduct pilot studies in the population of interest to determine whether precautions are adequate and appropriate, whether cameras are acceptable, and whether camera-related risks are appropriate relative to benefits.
3. Investigators should systematically collect and publish information on camera-related risks (e.g., negative reactions from bystanders), including adverse events (e.g., legal consequences).
4. Designers of wearable cameras for use in research should consider designs that minimize risks to participants. This should include not only physical inconvenience, but also risks related to participant and bystander privacy. For example, investigations of diet may benefit from a wearable camera system that includes chewing and swallowing sensors (Alharbi et al., 2017), where images are captured automatically only during and immediately after a chewing or swallowing event. Capturing only the experiences being investigated would reduce the likelihood of images containing identifying or sensitive information from participants or bystanders.

There are several limitations to this review. First, this review relies only on *reported* findings. It is possible that investigators took camera-related precautions and encountered camera-related risks not reported in the relevant papers. Additionally, due to variation in the types of risk-related findings that studies reported, it was not possible to quantify the frequencies of camera-related risks. Second, we chose to exclude findings related to experiences of *viewing* wearable cameras images, and instead reported only on experiences with *using* wearable cameras. However, findings pertaining to viewing the camera images suggested potential benefits. Participants from four studies reported that they were "fascinated" by the technology (Carlson et al., 2015; Kerr et al., 2013, 2016), preferred the camera to a travel diary (Kelly et al., 2011), and found the cameras helpful to their dietary recall (Arab et al., 2011). Third, although our review used clearly defined search terms and eligibility criteria, it does not meet all criteria of a systematic review. For example, we summarized information from all studies, rather than only information from high-quality studies, since none of the quality assessment measures examined by the first and last authors were appropriate to the review's aims. Thus, quality limitations, such as bias, may have

affected the results reported here. For example, results reported for studies with participant attrition may not fully capture the experiences of those studies' participants, including risk-related experiences. Also, although we searched multiple databases using broad search terms, our search likely did not identify all eligible articles. Further, our review did not include studies that were unpublished or were reported in a format other than journal article or dissertation. Additionally, only articles published before April 1, 2018 were included in our review, and more recent articles may provide important information relevant to our aims. A fourth limitation is that our review did not include cameras that recorded video or audio. Conclusions about the precautions and risks of research with video and audio devices should not be based on the present findings because the capture of video and audio poses unique legal and ethical risks beyond those posed by the capture of still photos (see Cychosz et al., 2020 for a discussion of ethics regarding audio recordings in behavioral research). Lastly, although some studies in our review did report participants' identified race and ethnicity (e.g., Nebeker et al., 2016), this information was not consistently reported across studies. Thus, our review does not provide information on whether risks may be higher for certain participants.

In conclusion, information reported in published studies suggests a low level of risk to individuals participating in research with wearable cameras, with participants primarily reporting concerns with physical inconvenience and discomfort in certain situations. No studies reported serious adverse events, including events related to participant or third-party privacy. It is worth noting that precautions that are essential for preserving autonomy and reducing risks (e.g., the voluntary nature of participation, disabling the camera in certain situations where privacy is required) may reduce the representativeness of the sample or the information captured. However, in areas of investigation where wearable cameras have clear potential benefits (e.g., due to well-documented and substantial limitations of more standard assessment methods), using wearable cameras to examine daily experiences, with appropriate precautions (Kelly et al., 2013), appears reasonable in the context of the risks reported in empirical research.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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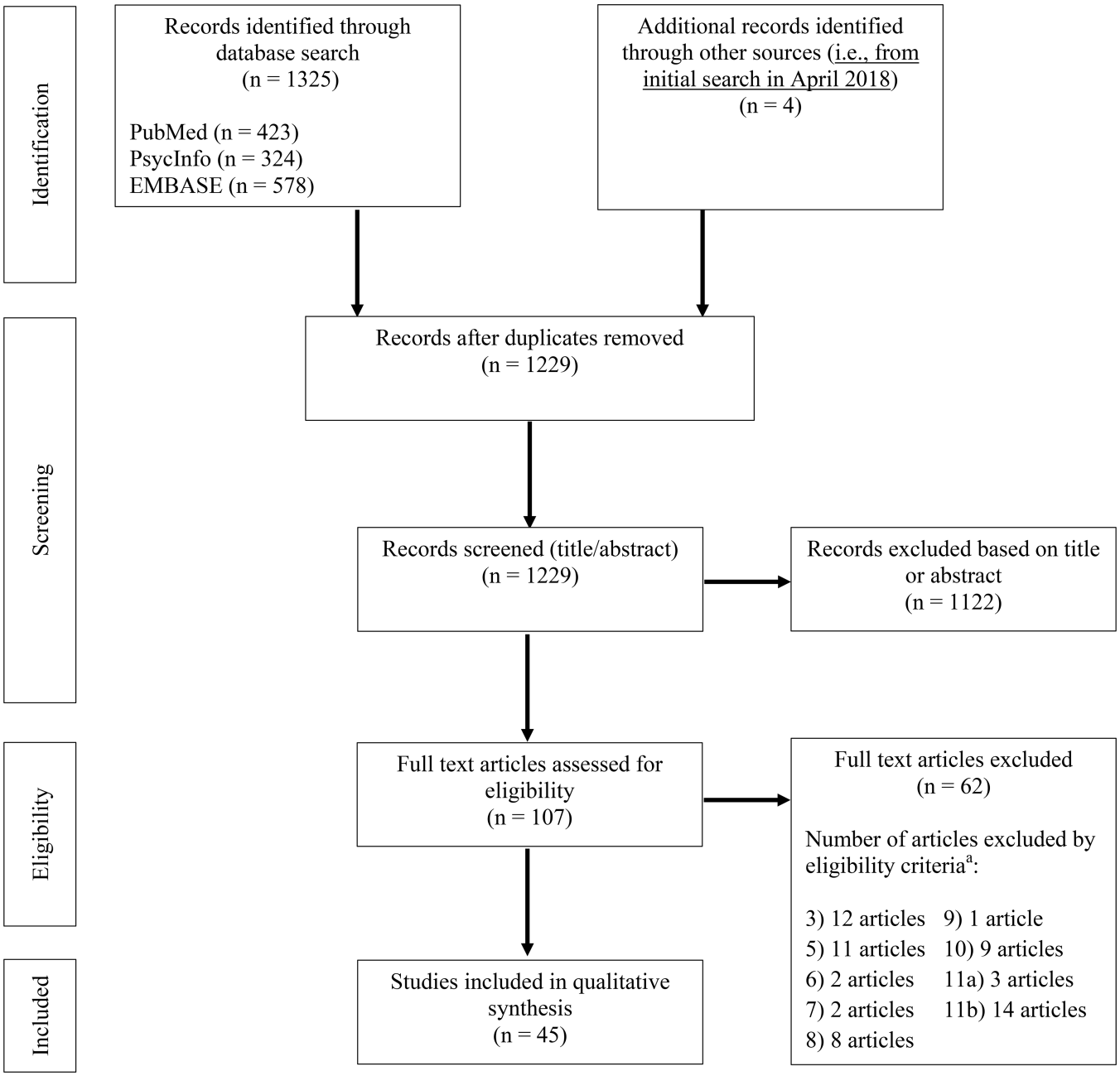

Figure 1.
PRISMA chart.

[a]Please see the text for the definitions of the eligibility criteria, referred to here by number. Eligibility criteria were ordered starting from general to specific, and reviewers selected the first reason in the list that a given article was not eligible. Thus, articles could have been excluded for more than one reason.