Wearable Cameras in Health
The State of the Art and Future Possibilities

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Introduction

The relationships between lifestyle behaviors and health outcomes usually are based on self-reported data. Such data are prone to measurement error. In response, there has been a movement toward objective forms of measurement that have low participant and researcher burden. The papers in this theme issue in the *American Journal of Preventive Medicine* assess the utility of a new form of objective measurement in health research, namely wearable cameras.[1–5] These devices can be worn all day and automatically record images from a first-person point of view, requiring no intervention or attention from the subject or the researcher. The most mature visual lifelogging device is Microsoft's SenseCam, a wearable camera worn via a lanyard around the neck.

The SenseCam has been increasingly used in health-related research for several years. These theme papers[1–5] report current research into wearable cameras in health, as presented at the SenseCam 2012 Symposium. Wearable cameras and their associated software analysis tools have developed to the point that they now appear well suited to measure sedentary behavior, active travel, and nutrition-related behaviors. Individuals may recall events more accurately after reviewing images from their wearable cameras. Aspects of their immediate cognitive functioning may also improve.

Despite the benefits of wearable cameras, there are still challenges remaining before their use becomes widespread. Ethical and privacy concerns are important issues that need to be addressed, as well as easy access to devices. In response, an ethical framework and smartphone-based wearable camera capture platform are proposed.[5] In sum, this body of work suggests that the use of wearable cameras will soon be appropriate to understand lifestyle behaviors and the context in which the occur.

Identifying Lifestyle Behaviors

Lifestyle behaviors consistently are associated with morbidity and mortality rates for a number of noncommunicable diseases.[6] These associations between behavior and health usually are based on self-report, a subjective form of measurement that is prone to error associated with recall, comprehension, and social desirability bias.[7,8] In response, there has been a movement toward objective forms of measurement that have low participant and researcher burden. Accelerometers are popular in physical activity measurement,[9] whereas camera phones have become common in dietary assessment.[10]

In these theme papers,[1–5] the utility of wearable cameras in observational health is presented from a number of viewpoints. We reflect on the development of wearable camera technologies and their subsequent transition to use as health research tools, and discuss a number of relevant topics such as applications in preventive medicine and inhibitors to the further adoption of wearable cameras, to set the scene for the other articles in this issue.

A History of Wearable Cameras

Wearable cameras emanate from research efforts in the field of lifelogging. Lifelogging refers to the digital capture of a person's everyday activities, from a first-person point of view in an unobtrusive and passive fashion.[11] Inspired by some early visionaries and pioneers,[12,13] initial work in the area focused on hardware miniaturization and data storage.[13,14] Recent advances in storage, sensor, and processor technologies naturally have led to compact and robust digital recording devices. The most mature visual lifelogging device is the SenseCam,[15] a wearable camera worn via a lanyard around the neck. This device captures an image approximately every 20 seconds, when

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triggered by sensors that log temperature, movement, light, and passive infrared data.[15]

The SenseCam has been used increasingly in health-related research for the past several years. SenseCam images have been shown to operate as powerful autobiographic retrieval cues by the neuroscience community.[16] Until recently, much memory-focused lifelogging work has concentrated on rehabilitation of those with cognitive impairment, with positive results.[16,17] SenseCam images also appear to support rehabilitation from acquired brain injuries through facilitating patient reflection and reminiscence.[18]

SenseCam images also can support other kinds of research. For example, in public health a methodology has been proposed to assess the error inherent in self-report with respect to active travel.[19] The range of cross-disciplinary interest in SenseCam has resulted in the creation of a series of SenseCam Symposia. These events have taken place in Chicago (October 2009); Dublin (September 2010); and Oxford (April 2012). Across these three symposia, a steering committee has selected 53 oral presentations from a range of disciplines (Table 1). Improving software tools to manage the increasing volumes of SenseCam data has remained an important topic throughout the series.[20] Meanwhile, initial SenseCam studies exploring the device as an aid to support autobiographic memory are being complemented by studies measuring health behaviors, such as diet and physical activity in healthy individuals. As such, this technology is relevant to health research. This issue contains five relevant papers from the SenseCam 2012 symposium that have been selected and expanded.[1–5]

Wearable Cameras for Monitoring Behavior and Influencing Well-Being

In certain instances, wearable cameras appear to offer an improvement over existing state-of-the-art objective measures of lifestyle behaviors and the contexts in which they occur. Measuring health-related lifestyle behaviors at the population level is important to influence policy and design downstream interventions.[21] Cell phones and small customized "eButton" devices have been used to support more complete recording of dietary habits.[10,22,23] The SenseCam has been used in pilot studies and suggests that self-report may be appropriate for measurement of active travel at the group level but not at the individual level.[19]

This theme issue further highlights the potential utility of wearable cameras for measuring sedentary behavior and nutrition-related behaviors, as compared to accelerometers[4] and self-report. Kerr et al.[1] note that wearable cameras have advantages over accelerometers as a criterion measure to understand the type and context of sedentary behaviors in free-living conditions. O'Loughlin and colleagues[2] recognize inherent flaws associated with accurately measuring diet-related behaviors through the use of either self-report or manual photo capture. With the support of wearable cameras, they have found that participants could provide a more accurate estimate of total energy intake.

There may be an improvement in immediate cognitive functioning for healthy individuals when reviewing images from wearable cameras. Clinical case studies have demonstrated dramatic improvements in autobiographic memory recall when reviewing lifelog images as noted by Silva et al.[3] However, these authors have now identified that the effect of reviewing wearable camera images may improve immediate cognitive functioning in some groups of healthy individuals as well.[3]

Challenges in Using Wearable Cameras

There are a number of challenges for researchers to consider when using wearable cameras in observational health research. The authors in this theme issue have identified specifically the following issues: difficulty in getting large sample sizes, poor operation of the camera in areas of low lighting, the time-consuming analysis onus on the researcher, incorrect positioning of the camera, and variability in subject compliance.[1–4,19] It may be possible to mitigate the last two challenges in future research efforts using wearable cameras by encouraging participants to wear a camera at chest level or higher[2] and ideally provide incentives to increase compliance.[1] Although current wearable cameras inherently will struggle in dark environments,[24] the issue of time-consuming analysis may ease as automated techniques to recognize lifestyle behaviors from lifelog images mature.[25]

Among the most significant barriers to widespread use of wearable cameras are ethical and privacy concerns. All

Table 1. Number of presentations from each discipline area at three SenseCam symposia

	2009	2010	2012	Total
Memory	9	6	2	17
Computing	6	2	5	13
Physical activity	2	1	5	8
Ethnography	1	2	2	5
Ethics	1	2	1	4
Rehabilitation	1	1	1	3
Market research		1	1	2
Nutrition	0	0	1	1

research reported in this theme issue has received ethical approval from relevant institutional ethics boards. However, when wearable camera research has been presented in conferences across scientific domains, the issue of ethics and privacy is often raised. Kelly et al.[5] have elaborated on the specific issues raised and have proposed an ethical framework for wearable camera research. This is the first such proposed framework and should serve as a checklist for those observing health behaviors using wearable cameras.

One final area that has been highlighted as inhibiting adoption of wearable cameras in some domains is the limited availability of suitable devices. The Vicon Revue (viconrevue.com) has been used by many researchers, but for some the £300 (US$477) unit price is limiting. In response, Gurrin and colleagues[4] present a wearable camera platform for research, which is based on a smartphone. Android smartphones are now available for under £100 (US$160), and are already in wide use. The cell phone may have limitations as an image-capture device because of its being used for other functions. A variation on this approach is a wearable camera that connects wirelessly to a smartphone.[26] Combining such hardware devices with Gurrin's cell phone software platform[4] may be a route to provide ubiquitous access to wearable cameras for health research. We hope that ultimately such cheaper devices may help address health-related issues in developing nations.

Conclusion

Wearable cameras are becoming viable for the observation of lifestyle behaviors. The hardware and software has been improved iteratively in the computer science community for the past 20 years. Recent devices are now practical to use in health research, as demonstrated in these papers.[1–5] It is acknowledged that further development of ethical frameworks and improvements in data-management procedures are required. However, initial findings demonstrate that wearable cameras can be an important new methodology in observing and understanding participant behavior and the context in which it occurs.

A drawback of some public health interventions is that the participating individuals often tend to perceive small benefits to population strategies for disease prevention.[27] Perhaps the highly stimulating nature of reviewing wearable images[3] and the ability to personalize feedback[23] could mean that wearable cameras can provide support as a lifestyle behavior change catalyst.

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