WillSense: Adherence Barriers for Passive Sensing Systems That Track Eating Behavior

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CHI'17 Extended Abstracts, May 6-11, 2017, Denver, CO, USA.
ACM ISBN 978-1-4503-4656-6/17/05.
http://dx.doi.org/10.1145/3027063.3053271

Abstract
Energy balance is one component of weight management, but passive objective measures of caloric intake are non-existent. Given recent success of actigraphy as a passive objective measure of the physical activity construct that relieves participants of the burden of biased self-report, researchers are aiming to find a passive objective measure of caloric intake to improve understanding of problematic eating behaviors in participants with and without obesity. Passive sensing food intake systems have failed to go beyond the lab and into behavioral research in part due to low adherence to wearing passive monitoring systems. This paper presents preliminary results in participants with and without obesity performing structured and unstructured eating experiments to understand wearable adherence as affected by: 1) perceived data privacy; 2) stigma of wearing devices; 3) comfort. Wearables examined include neck- and wrist-worn sensors, and video camera-based systems.

Author Keywords
Wearables; eating detection; passive sensing; privacy; stigma; comfort

ACM Classification Keywords
Human-centered computing Empirical studies in ubiquitous and mobile computing; Security and privacy Usability in security and privacy []

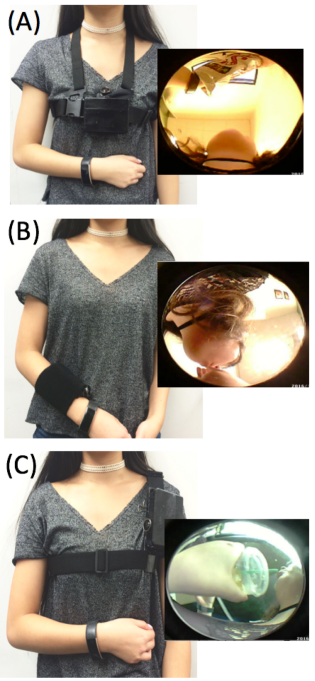

Figure 1: Three camera locations used in the study: (A) chest, (B) wrist and (C) shoulder

Introduction

Studying eating behaviors of participants with and without obesity is essential to understanding problematic eating behaviors to bridge the gap to intervention design. Food frequency questionnaires, food diaries, and 24-hour dietary recalls are the main measures of food intake. These self-report methods are predisposed to bias in recall and response, imposing a high burden on participants, especially longitudinally. Passive sensing wearable technology has the potential to detect how (number of feeding gestures, swallows, and eating duration), where (at home, a restaurant), when (time of day), and with whom (alone, or with friends or family) people eat. These systems could reduce participant burden, and gather data in natural contexts. Numerous studies have designed wearables [12, 5, 1] or have used commercial wearables [14, 10] to detect eating behaviors. To detect eating behaviors, passive sensing data analytic models are developed to process data from wearables. In order to build accurate models that reliably detect behaviors in free-living populations (outside the lab), participants must adhere to wearing the sensors in order to provide reliable ground truth against which these models are built.

The purpose of this study, WillSense, is to examine the challenges of using eating related wearables particularly related to participant privacy, perceived stigma, and user-comfort, which impact adherence to wearables (keeping participants wearing the sensor suite for longer periods to capture true eating habit), culminating in an optimal passive wearable sensor suite for fine-grained eating detection that participants are likely to wear in the field.

Background and Related Work

To obtain eating moments ground-truth, Dong et al. [4] use a smartphone app for free-living participants to log the start and end of their eating moments to establish ground truth for a day. Ten participants (23%) were excluded due to low reporting compliance and missing meals. To avoid these problems, cameras have been used to provide objective course detection of eating moments ground-truth [15, 2]. Thomaz et al. [14] asked participants to don a camera on a lanyard to capture a still image every 60 seconds to aid in end-of-day eating recall. This minimized participant burden throughout the day, but the images do not capture fine-grained activities that occur at a second or subsecond scale. An average duration for a feeding gesture is 2.8 seconds (from the time of food pick up to bite, and hand back-to-rest) [17].

Cameras have also been used by life-loggers. Hoyle et al. [7] studied how sharing images in social networks among life-loggers using a mobile phone to capture an image every 5 minutes impacts concerns of privacy. Raij et al. [11] showed that people were concerned with divulging their physiological state (stress) and method of commuting to and from work, but less concerned with sharing data with researchers compared to the public. The researchers examined privacy issues with psychological and behavioral data captured by wearables only.

King et al. [8] investigated the stigma of a wearable camera (SenseCam) and a wrist-worn sensor (LARK) using Tobii eye-tracking glasses to count the number of fixations participants had on the devices. While results of tracking eyes show promise of low intrusion and stigma in-lab, perceived stigma may be sensed differently in real-world contexts.

The WillSense study aims to build upon this related work by addressing adherence (privacy, user comfort, and stigma) of using a wearable device to collect fine-grain eating behaviors outside of a controlled laboratory setting in people with obese, overweight and normal BMI.

Figure 2: Choices of neck-worn devices (1:Phiten, 2:Lace, 3:Velvet, 4:3D Printed, 5:Fabric, 6:Throat Microphone)

WillSense System

WillSense system is an eating episode detection and characterization suite that comprises three wearables: video camera, neck-worn sensor, and a wrist-worn sensor. To mitigate basic privacy concerns while enabling ground truth labels for validation of machine learning algorithms a web-based deletion and annotation interface (DAT) was designed to view, delete and annotate video data with start and end times of eating episodes. DAT helps facilitate end-of-day dietary recall.

Video Camera Design

Three prototypes of a wearable video camera (with audio) were designed (with an augmented fish-eye lens) to continuously record participant behavior to capture fine-grained eating activity. Placement of a video camera in different positions around the upper torso of the body and wrist provided different fields of view, varying the ability of the system to capture different eating-based features. Figure 1 depicts the three designs worn by a participant along with their corresponding fields of view. We aim to understand if the location of the wearable camera can affect the participant comfort, perceived stigma, and privacy.

The shoulder camera lens faces the participant's dominant hand rather than pointing outward, to minimize bystander discomfort, although bystanders to the side of the participant are noticeable. The chest-worn camera lens is directed at a 45-degree angle from North (up), although this was later adjusted for participants with obesity. In this design, the lens would capture bystanders directly in front of the participant. The wrist-worn camera lens is positioned on the inner side of the dominant hand's wrist at a 45-degree angle away from the wrist.

Neck-Worn Sensor Design

Figure 2 illustrates the six neck-worn sensor prototypes that were provided as options for the participants. Some styles were commercial (like the throat microphone), other styles were designed in the lab, equipped with a piezoelectric vibration sensor and a microcontroller board capable of sampling and transmitting sensor data to a mobile phone via Bluetooth.

Wrist-Worn Sensor Design

The historical nature of wearing a wristwatch lends itself to the implementation of a wrist-worn device. Given Microsoft Band 2 (mBand2) [3] open API platform enabling researchers to access raw sensor data, this paper focuses on using the mBand2 to test the potential for adherence to a wrist-worn sensor. The wrist-worn device is worn on the dominant hand to increase the likelihood of detecting an eating gesture.

Experiment Setup

This study was approved by Northwestern University IRB (Protocol #STU00203801). The study comprised 13 participants (6 obese, 8 female, mean age 32.8 yrs, std 12.5). Before the study, participants were screened for eligibility (age > 18, normal 18.5-25, overweight 25-30, obese > 30 BMI), answered questionnaires about problematic eating habits (emotional[16], impulsive[13], hedonic[9] and binge eating[6]), and privacy attitudes which may impact their use of wearables.

The study comprises structured and unstructured eating settings. In the structured setting, participants were assigned a random video camera design (either chest, wrist, or shoulder), the mBand2 wrist-worn sensor and the neck-worn sensor design of their choice. Participants were then asked to perform a sequence of activities (see Table 1) that

(1)	Walk on Michigan Ave & Observe people's reaction, ask a stranger for directions.
(2)	Eat at home or restaurant or cook meal and eat
(3)	Go to coffee shop & Order a cup of water and drink
(4)	Go to bathroom & Use restroom turning off and removing the camera before going in, and turning it back on when coming out.
(5)	Check email & Write an email saying hello in the subject line to the researcher's email covering or turning off the camera before entering user password
(6)	Go to an ATM & Check account balance covering or turning off the camera before entering the password
(7)	Look at a mirror & Look at reflection from head to toe

Table 1: Structured activities that the participants did for the first hour

may affect their level of privacy, perceived stigma, and comfort. They were requested to take notes in a diary while out in the field and carried an explanation card to hand to strangers asking about the devices. Participants then took 2-4 hours performing activities of their choosing to capture a wider variety of activities.

After returning to the lab, they were asked to try on the other two video camera designs for 10-15 minutes while performing the following activities around the lab: walk to the super market, check email, eat a snack, and looking at a mirror. After trying each camera design, participants were asked to complete a survey to measure the effect of each camera design on privacy, perceived stigma, and comfort.

The participants were then instructed to review the recorded video for each camera design using DAT, delete any part of the video they did not want anyone to see, and annotate the ground truth eating episodes. After viewing their recorded video, they repeated the questionnaire to assess whether perceptions had changed after seeing themselves recorded. Participants were then asked to rate DAT ease of use, ranked the camera designs' wearability, and answer a new set of questions related to data privacy, stigma and willingness to wear the devices (paid or unpaid).

As the participants were viewing their videos and answering survey questions, the research coordinator was monitoring participant response remotely and preparing further questions to seek more clarification. Those questions were discussed with the participant in the final interview phase.

Preliminary Evaluation

Only one of the participants owned a wearable device. 6 participants exhibited at least one of these problematic eating episodes: emotional eating (n=5), hedonic eating (n=5) and a high likelihood of binge eating (n=6). All participants used social media, and 63.6% reported they are at least somewhat private in sharing information. All participants used social media, and 45% reported they are at-least somewhat private in sharing information. Below we summarize the main themes and concerns that we found when coding the participants' response in the surveys and the interview.

Privacy: Disclosure of Eating Habits

In discussing preconceived privacy concerns of participants, there was a clear difference in concern between people who were overweight compared to people who were of normal or obese BMI. In response to reporting to others when participants over- or under-ate, participants who are overweight were significantly more concerned than others ($t=2.09$, $p = 0.049$), and the same is true regarding reporting the number of eating episodes per day day($t=4.1$, $p =0.032$), suggesting a challenge in self-report for participants that are overweight over other participants. Privacy concerns also differ depending on the group data is disclosed to. Participants that are overweight were more concerned than others with reporting data to family and friends, suggesting the potential benefits of incorporating a role for the family in weight interventions for participants with obesity, but not necessarily for participants that are overweight. The majority had no issue reporting data to researchers, doctors, and trainers/dietitians.

Privacy: Enabling Full Control

36% of the participants said that they took off, turned off or covered the camera in situations other than the use of ATM or bathroom. One participant was asked to take off the camera when volunteering at a school around students, about a third of the participants (n=4) covered or took off the camera before approaching a private matter (e.g. talking to the doctor, entering passwords). Only one participant

requested to delete their video. This suggests that participants prefer to ensure private matters are never recorded, in case they forget to delete, which may pose a challenge in longer studies if participants forget to wear or turn back on recording later.

Privacy & Stigma: Bystander Reaction Concerns
Participants expressed pre-study concerns to wearing the video camera, especially related to explaining it to bystanders reacting to being videotaped. One participant reported: "I was mostly concerned that other people I interacted would have privacy issues and ask me questions and I wouldn't know how to explain." However, these concerns diminished after performing the activities. The same participant later reported that "it got more comfortable as the day went on and I didn't really mind it as much especially since most people didn't really seem to be bothered by the camera." Participants asked about the video camera by bystanders who knew them (30%) either explained the details of the research or provided them with a research explanation card as instructed. No phone calls or concerns from bystanders were received by the research coordinator.

Stigma: System Mistaken for Ulterior Motives
Three participants were concerned the video camera on the shoulder or chest might be mistaken for a bomb. They were concerned the police might stop them. One participant said: "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". The participants reported that the strap design, camera size, and camera color were the main cause for their anxiety. We are in the process of a new design that does not provoke such anxiety in the participant.

Stigma: Depends on the Environment
Participants have reported that it is very normal to wear a wrist band or an activity tracker, and reported that people might not react as much toward the camera because the test was done in a metropolitan area (downtown Chicago), where people are used to seeing a large variation in peoples' clothing and adornments. Participants did feel, though, that these devices would garner further stigma in environments with less diversity.

Comfort: What Makes a Wearable Comfortable?
Participants responses were coded in order to understand what makes a wearable design comfortable. For the neck- and wrist-worn sensors, the design needed to 1) match their clothing or allow customization; 2) look like existing popular commercial wearables; 3) be aesthetically pleasing; 4) be easy to adjust, and 5) be stable on the body.

As for the video camera, participants wanted control over the camera by being able to take it off or cover it without removing the harness. The video camera should feel secure on the body to allow for any kind of movement without throwing off their center of gravity (e.g. while running). Some participants mentioned preferring a video camera design that does not stand out, having it embedded as part of a t-shirt, necklace or wrist band. With the video camera, participants felt concerned about discussing the camera with others or obscuring its field of view when interacting with other people. Some participants felt it awkward or suspicious if others found out they were wearing a hidden video camera. However, it felt more acceptable to participants if the camera was hidden and only captured the wearer's face.

Comfort: Camera Position Preference
When asked to rank the video camera system they would be willing to use for a two-week study, the wrist camera was the winner (as first choices, cameras ranked 43% wrist, 29% shoulder, 21% chest, and 7% chose none). Four participants said they would not wear the chest camera. More

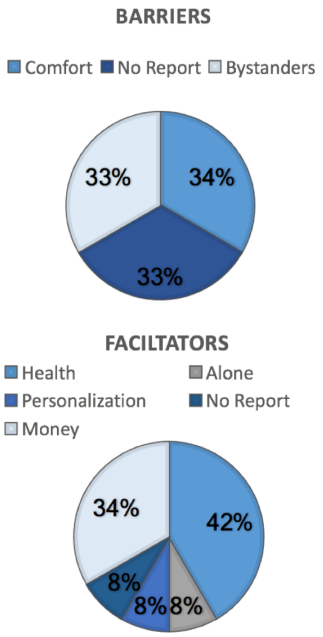

Figure 3: Facilitators and barriers to adherence

men than females preferred the wrist camera. Women are more used to wearing chest undergarments possibly making then more accustomed to the feeling of a chest strap. The participants that selected the wrist camera selected it because it is hidden and people can control the camera field of view better than other designs. Participants who selected the chest camera as their first choice selected it because they thought that the weight was more evenly distributed. The participants who reported the shoulder camera as their first choice selected it because its video footage was best for privacy, or it was easier to wear.

Labeling: Videos aid in dietary recall
Participants were able to find and annotate 98% of their meals using the DAT system, particularly from video recorded through the chest and shoulder cameras. Participants reported slight difficulty labeling eating moments from the wrist video camera due to the rapid change in orientation due to the continuous motion of the wrist sensor (requiring more time).

Labeling Cues
Some participants remembered roughly the time that they ate during the day and then navigated to the predicted hour in the video. Others relied on sequence cues; they remembered that they ate after doing a particular activity (like shopping) or before going to the bank. Others used context cues like logos and music to identify their location to decide whether they ate there or not. We hope to incorporate algorithms that identify these cues automatically in future iterations of the DAT system.

Labeling: Challenges of Drinking Labels
Drinking moments were difficult to label as they occurred sporadically throughout the day. One participant would take one or two sips throughout the day, making it difficult to locate by glancing through the recorded video. In future iterations of DAT we will incorporate real-time machine learning models that may aid in providing cues for episodes of drinking.

Adherence: If the Price is Right
When asked, 82% of the participants agreed to wearing the wrist- and neck-worn sensor for 30 days during waking hours if paid $100. 82% were also willing to wear the entire system for 30 days if paid $100, and were able to keep the equipment at the end of the study. Figure 3 shows the coded motivators for wearing the devices. Participants with obesity were inclined to wear the device for more days if paid or if it could help them become healthy, perhaps showing hope that such a device could help them maintain or lose weight.

Conclusion

This paper presents initial steps in understanding barriers and facilitators to adherence of wearables in obesity research, especially wearable cameras and neck- and wrist-worn sensors. These findings suggest that participants manage their privacy by covering, removing or turning off the camera rather than deleting video segments. Customization, size, attachment, ease of wear and aesthetics are factors that can affect wearables comfort which significantly impacts adherence. Also, perceived stigma regarding wearables may be greatly affected depending on the ethnic group studied and their environment. It also suggests the importance of money and improving participant health as facilitators to wearables' adherence.

Future Work

In a future study, we hope to incorporate greater number of individuals wearing the devices for a longer period of time, to capture other barriers and facilitators to wearable in eating-related research. We will also implement machine learning algorithms that will generate cues for the participants, aiding them in annotating their eating moments.

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