# Auracle: a wearable device for detecting and monitoring eating behavior

Shengjie Bi†, Ellen Davenport†, Jun Gong†, Ronald Peterson†, Joseph Skinner†, Kevin Storer*, Tao Wang†, Kelly Caine*, Ryan Halter†, David Kotz†, Kofi Odame†, Jacob Sorber*, Xing-Dong Yang†
**†Dartmouth College and *Clemson University**

## Introduction

**Motivation**: Use technology to track and understand eating behavior, in support of eating-behavior research.

**Problem:** Health science has no effective means for automatically measuring eating behavior outside the lab.

**Goal**: Develop a wearable earpiece to monitor eating through a waking day, unobtrusively, in free-living conditions.

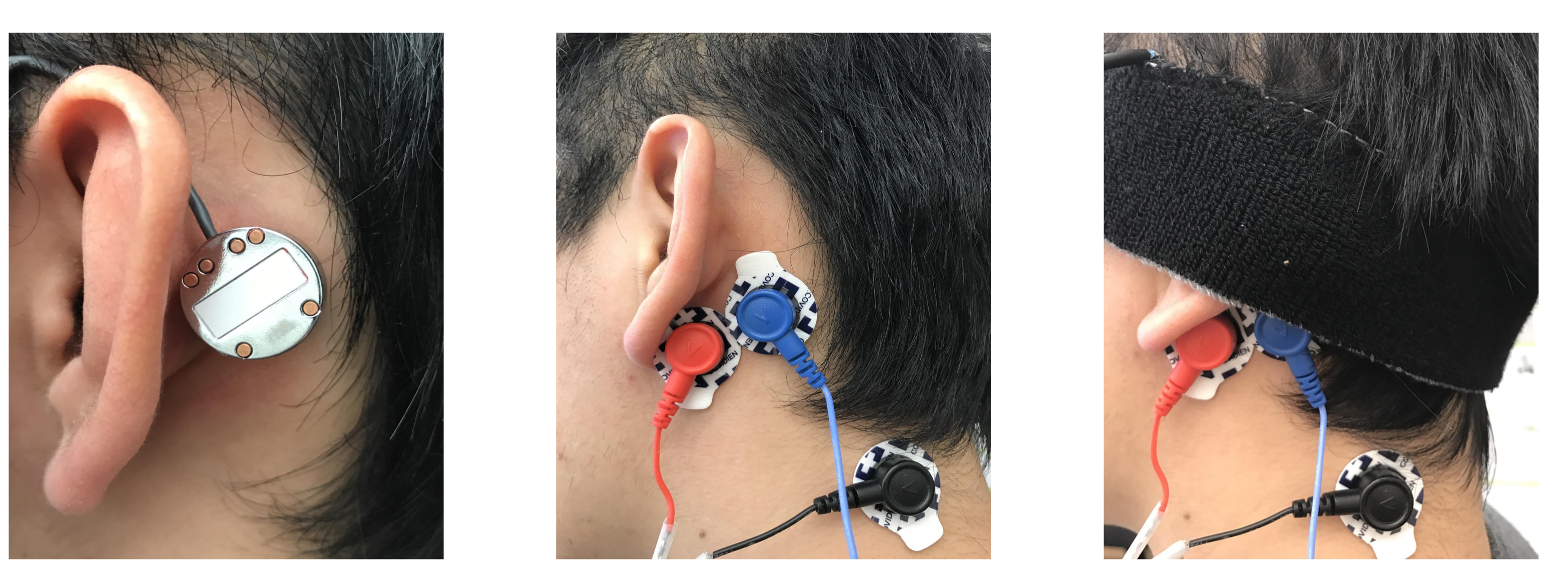
## Digital earpiece

**Bench-top apparatus**:
We used the following setup to select optimal sensors, features, parameters and classifiers for wearable devices.

Contact microphone → Data acquisition device ← EMG sensor

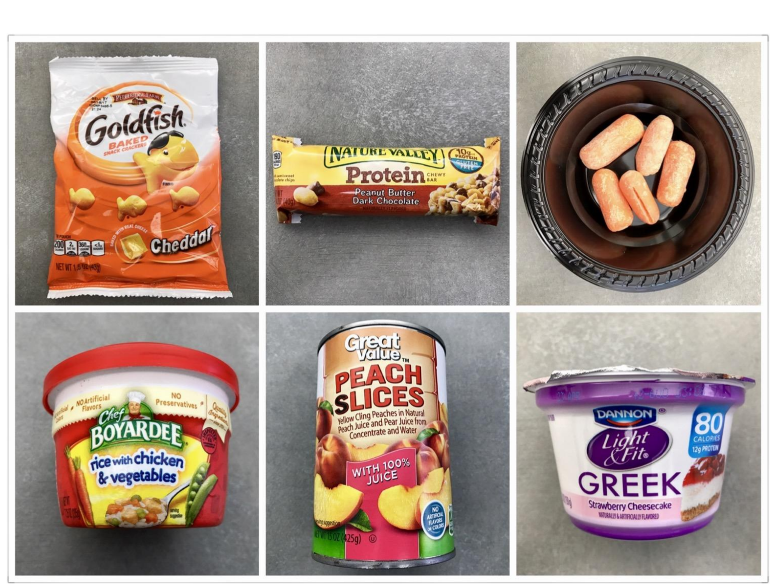
Data acquisition device → Laptop

Laptop: Feature extraction → Feature selection → Classification



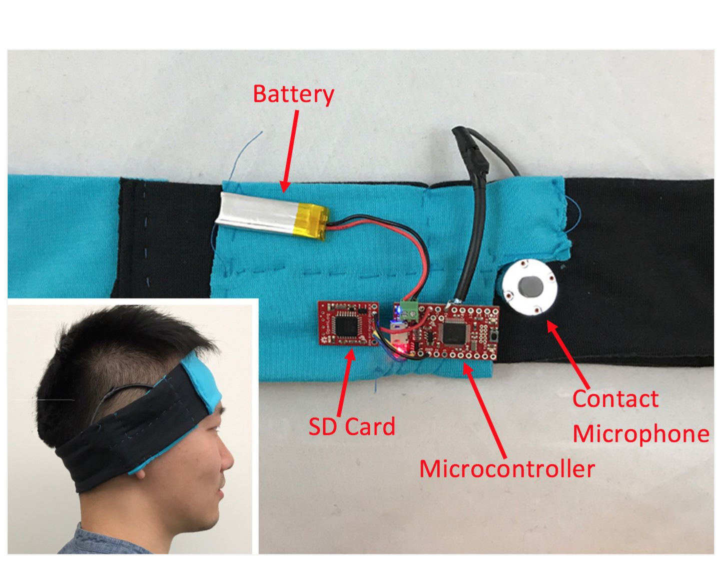
Placements for contact microphone, Electromyography (EMG) electrodes, and both sensors respectively.

We conducted a study with 20 participants. We collected data using both sensors for the first 10 participants and using contact microphone only for the second 10 participants. Each participant ate 6 types of food and performed 8 types of activities in laboratory conditions.




| Activity | Description | Duration |
|---|---|---|
| Eating | Eat a protein bar | 2 minutes |
| Eating | Eat several baby carrots | 2 minutes |
| Eating | Eat several crackers | 2 minutes |
| Eating | Eat canned fruit | 2 minutes |
| Eating | Eat instant food | 2 minutes |
| Eating | Eat yogurt | 2 minutes |
| Talking | Read an article aloud | 5 minutes |
| Silence | Relax and avoid chewing | 5 minutes |
| Coughing | Cough | 24 seconds |
| Laughing | Laugh | 24 seconds |
| Sniffling | Sniffle | 24 seconds |
| Deep Breathing | Deep breath | 24 seconds |
| Drinking | Drink water | 24 seconds |

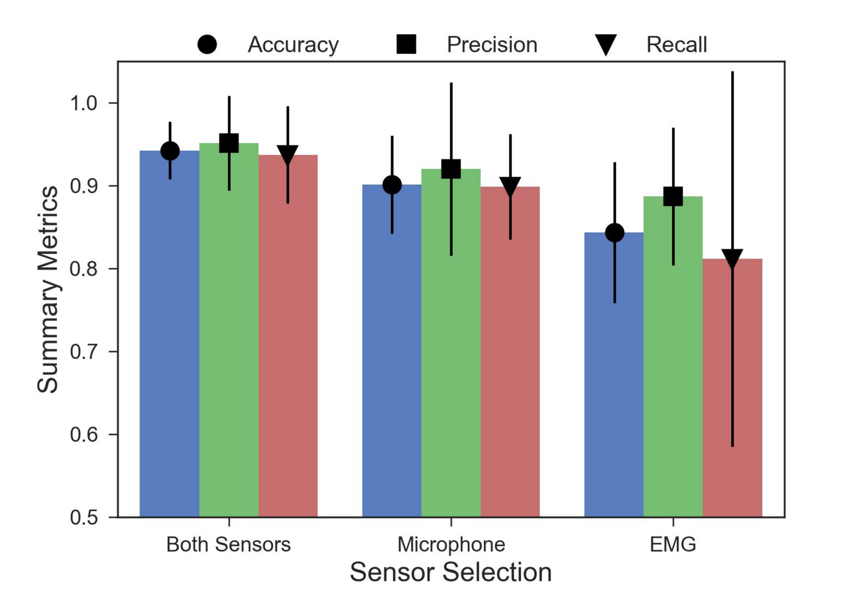
Food used, activity performed and duration for data collection.



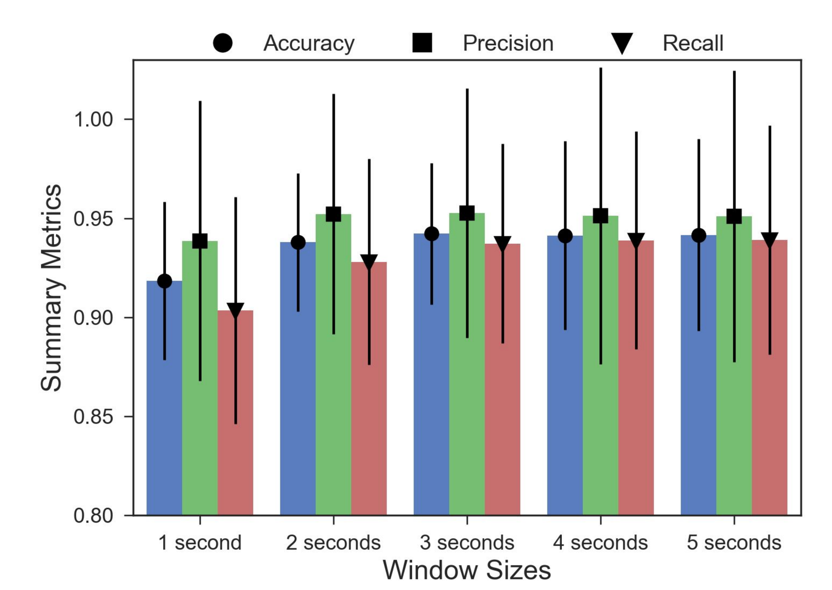

We fused the contact microphone, microcontroller, SD card and battery into a headband; we excluded EMG based on evaluation results and feasibility for free-living scenarios.

## Eating detection and sensor inference

Raw data was preprocessed and segmented into time windows with uniform length and 50% overlap. We used a two-stage classification model based on logistic regression. For each time window, we extracted features and compared the output of the classifier (*Eating* or *Non-eating*) against the ground-truth label. We used Leave-One-Person-Out (LOPO) cross-validation to evaluate our classifier's performance.



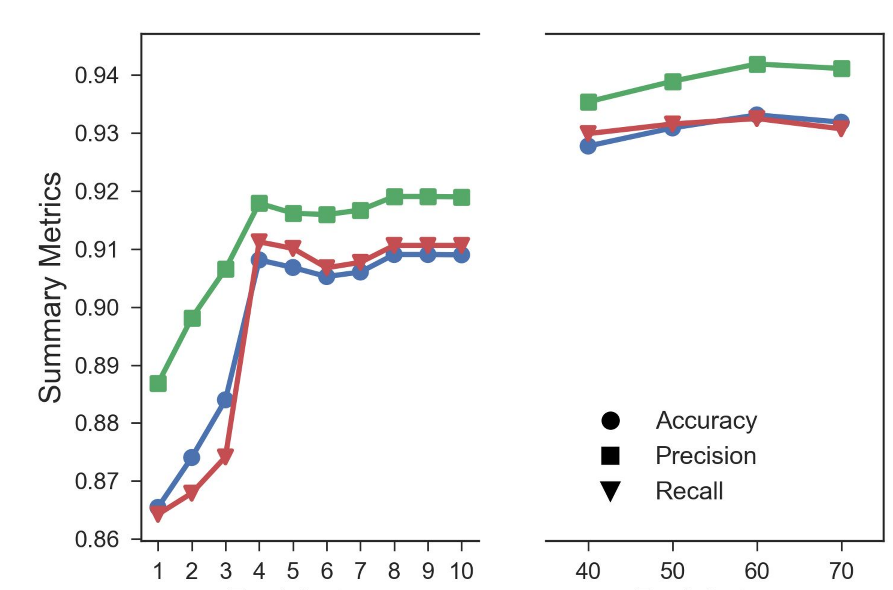

Results when using contact microphone and EMG, independently and combined.




Results with window size ranging from 1 second to 5 seconds

| Resolution | Accuracy | Precision | Recall |
|---|---|---|---|
| 24-bit | **0.942 ± 0.036** | **0.953 ± 0.063** | **0.937 ± 0.050** |
| 10-bit | 0.935 ± 0.043 | 0.943 ± 0.075 | 0.934 ± 0.052 |

Results with bit resolution of 24-bit and 10-bit




Results with number of features ranging from 1 to 70

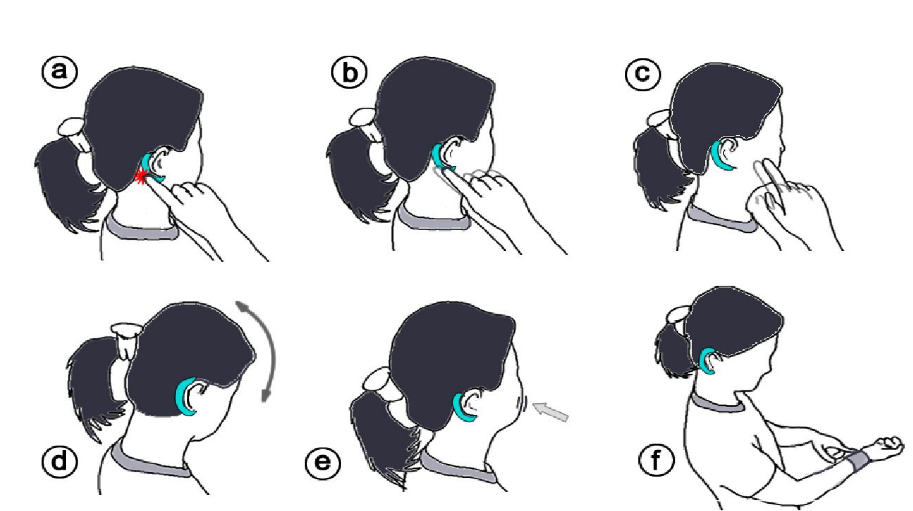
| Feature type | Description | Number |
|---|---|---|
| Kurtosis | Kurtosis | 1 |
| Mean | Number of values higher than mean | 1 |
| Sum | Sum over the absolute values of changes | 1 |
| Peak | Number of peaks at different width scales | 4 |
| Friedrich coefficients | Coefficients of polynomial h(x) fitted to the deterministic dynamic of Langevin model | 1 |

Top 8 features

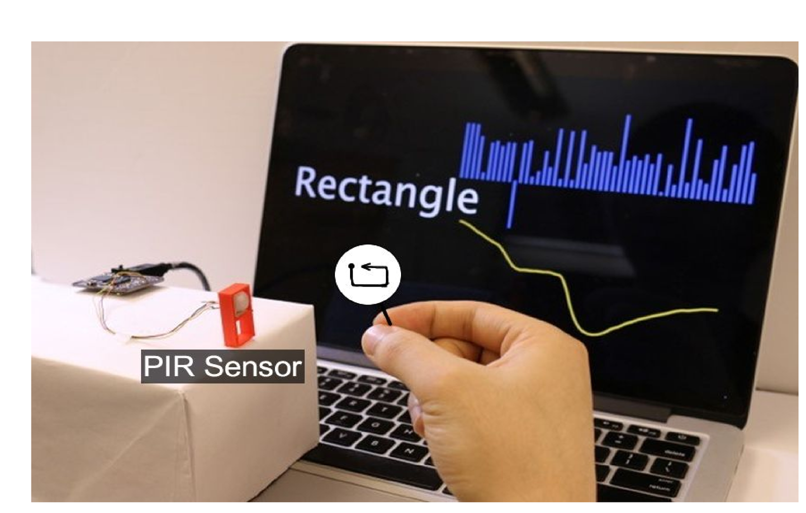
In LOPO experiments, we achieved accuracy over 90.9% with 500 Hz sampling rate, 10-bit resolution, 3-second window size and 8 features for eating detection of 6 types of food with different crunchiness level (3 crunchy and 3 soft).

## Human interface

To maximize the utility of an earpiece, the wearer should be able to interact with the earpiece efficiently and accurately, in ways that preserve the wearer's privacy and are socially acceptable in relevant situations. We include a variety of input and output capabilities in the proposed earpiece, allowing us to explore a wide range of interaction modalities, some conventional and some novel.




Earpiece interactions: (a) press a hardware button; (b) gesture input on the device; (c) gesture input on the cheek; (d) head gesture; (e) tongue gesture; and (f) use Amulet.




Near-ear micro thumb-tip gesture can be sensed using a PIR sensor, a modality we are just beginning to explore for the Auracle.

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