

Detection and analysis of smoking events with wrist-worn sensors

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Introduction

Smoking is a large public health problem. Many people want to quit smoking, but it is known to be difficult. The ultimate goal of the project is to find an effective way to help people quit smoking. There are currently no smoking prevention methods that leverage recent advances of technology such as machine learning, sensors and wearable electronics. The detection and intervention can be integrated into a tightly coupled feedback loop as shown in Figure 1.

We will focus on the detection: how to accurately detect smoking with just sensors worn around the wrist. Wrist-worn sensors can be integrated into a watch, which is especially relevant now with the surge of interest in smart watches (such as Samsung Gear, or Pebble Watch). Currently, there are no accurate and unobtrusive methods to detect the action of smoking, but very accurate detection is required for the intervention. Once, smoking event is detected intervention could be done by applying electrical stimulus to the hand, causing hand to open and drop the cigarette. Also, less invasively, wrist-worn sensor can alert by vibration or by emitting a sound alarm, or sending a message to a social network through a smartphone.

Smoking has an emotional component; it causes many emotions such as arousal, guilt and anxiety. We want to find if that emotional component can be leveraged in the combination with various sensors to accurately detect smoking. Furthermore, it will be interesting to see how skin conductance will change during smoking. Will it indicate arousal, or perhaps show no changes? How will it help detection? We hypothesize that the smoking will cause increase of arousal.

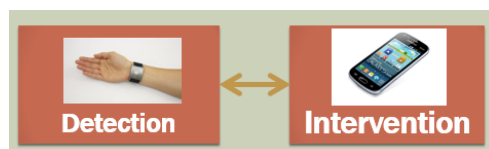


Figure 1. Detection and immediate intervention leveraging a smartphone

Previous work

Only recently researchers started looking into smoking detection methods, but there are still no practical methods to detect smoking. A study [1] done in 2012 used accelerometer worn on a wrist. The study achieved about 70% accuracy which is too low to be used in practice. There are many other hand movements that can be confused for smoking such as eating and drinking. Because there is no sensor that measures smoking behavior directly, it is not possible to achieve higher accuracy

using just one type of sensor. Likely, a combination of sensors is needed. For example, study [2] done in 2013 achieved about 98% detection rate using the respiratory plethysmograph, the wrist-worn accelerometer and the RF-based hand gesture sensor. Although, the accuracy is high, the approach required subject to wear a special vest, which is too obtrusive for real-world wearable applications.

The effect of smoking on skin conductance was studied intensely in the 1970's, but not much after that. A study [3] from 1974 found a large increase in arousal level after smoking. Unfortunately, that study, as all other studies during that period, was conducted in controlled laboratory conditions. Also, the subjects were told to abstain from smoking for 8 hours prior to the experiment, and were made to smoke large amount of nicotine during the experiment. In the 'wild' the effect of smoking on skin conductance might be different.

Methods

Subjects

Total of 13 subjects (3 females, 10 males, aged 22-44) were recruited. 10 subjects were everyday smokers and 3 were occasional smokers. 10 subjects were recruited at a physician's office, where they were undergoing an unrelated medical appointment. Other 3 subjects were students at MIT.

Measurements

Data was collected with Q-sensors (Affectiva) shown in Figure 2. Q-sensors recorded electrodermal activity (EDA) to the built-in flash memory. Additionally, Q-sensors recorded temperature and activity with an accelerometer. The Q-sensor was worn on the inside surface of the wrist of the dominant arm. Two different Q-sensors were used: 10 subjects were tested with the first Q-sensor and 3 with the second.

The data was analyzed offline in MATLAB software. For analysis, zero skin conductance readings were removed, since they indicated that EDA was too small, and below the resolution of the Q-sensor. Mean of 5 minutes before, mean of the smoking interval and mean of 5 minutes after smoking was used for further analysis.



Figure 2. Q-sensor as worn in this experiment.

Protocol

First, the subjects were asked to read and sign the consent form. After that, the Q-sensor was placed on the wrist of the dominant arm. The subjects were instructed to press the button on the Q-sensor right before starting smoking and after finishing smoking. This allowed us to find the smoking events in the raw data.

The subjects waited 5 minutes to acquire baseline readings, and then went outside of the building to smoke one cigarette. The outside temperature was about 5 degrees Celsius. When finished, subjects returned, and waited another 5 minutes. Finally, the Q-sensor was removed. At the end, subjects were asked how often they smoked. The whole experiment took about 20 minutes.

Additional experiment with dust sensor

We were interested if a dust sensor could be a good detector of cigarette smoking events. For testing we built a wrist-wearable and wireless dust sensor. But we did not include this sensor in the main protocol because of its large size. The Q-sensor and dust sensor could not be yet comfortable worn on the same wrist. Also, we worried that the large size of the sensor would interfere with the subject's natural smoking habits.

We used an optical dust sensor (Sharp GP2Y1010AU0F) connected to a microcontroller (Arduino Mini Pro) as shown in Figure 3. A Bluetooth modem streamed data wirelessly to a laptop computer (MacBook Pro, 2013 model). Electronics were placed in a 3D printed enclosure, and strapped to the wrist with a Velcro armband.

We tested on one subject when he smoked while standing outside. The weather was slightly windy. The dust sensor was worn on the wrist of the dominant arm and secured with a Velcro wristband.

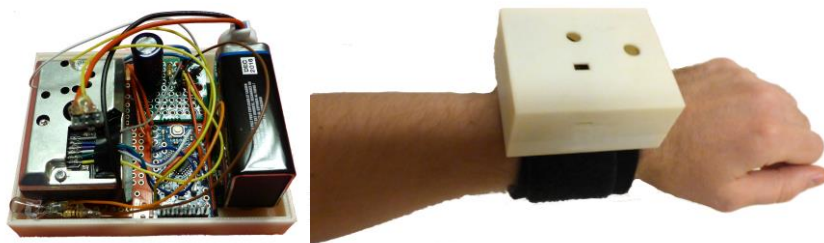


Figure 3. Wearable dust sensor without the top cover (left). The same sensor strapped to the wrist with top cover attached (right).

Results

Arousal level

The results from 12 subjects were used in the analysis. One subject was excluded because he forgot to record the time when he started smoking. Arousal level increased in 3 subjects during smoking. Furthermore, arousal decreased in 6 subjects, and stayed about the same in 3 subjects.

Statistical tests

We did a paired t-test to compare the mean before to the mean during smoking, and before-after smoking, and during-after smoking. The p-value for all combinations was too high to be statically significant.

Dust sensor experiment

The time-series data from the dust sensor is shown in Figure 5. The dust sensor was very sensitive to smoke; blowing cigarette smoke directly into the sensor caused it to saturate. Also, large peaks are seen when the subject is smoking.

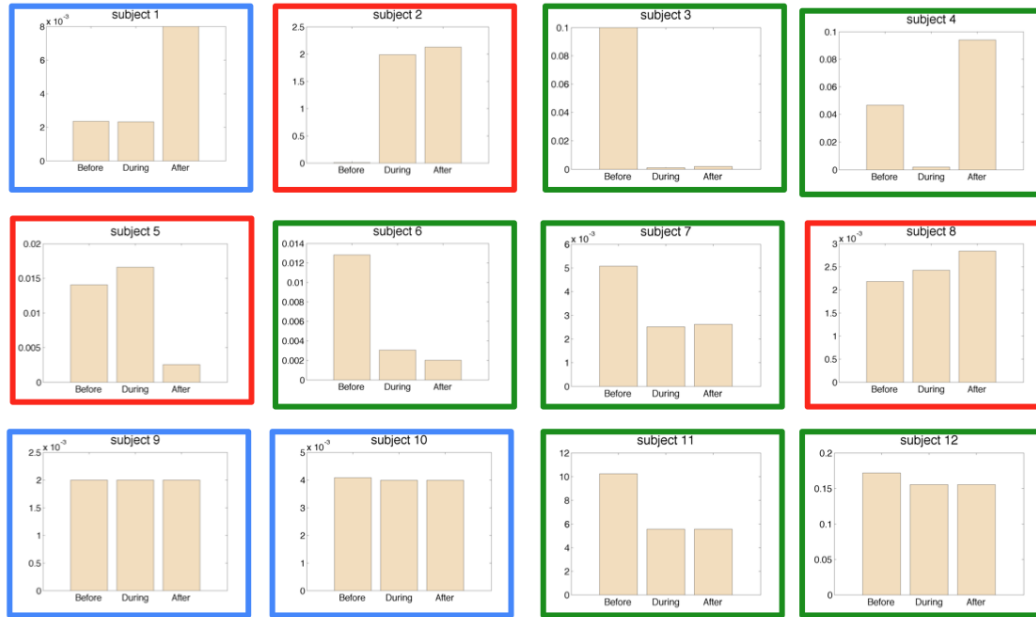


Figure 4. Mean before, during and after smoking. Blue outlines represent the same arousal level before and during smoking. The red outline mean increase of arousal during smoking. Green outline show decreased arousal during smoking.

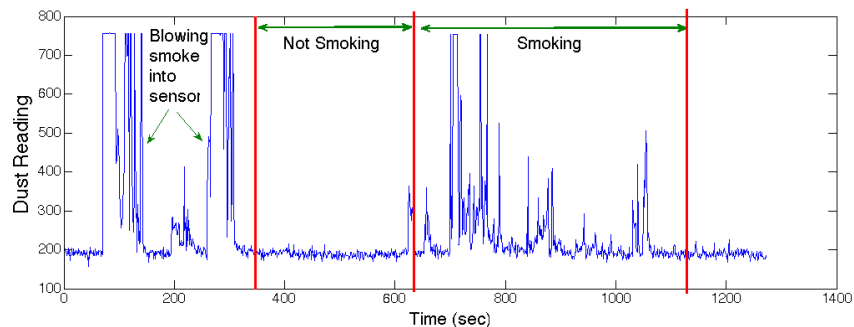


Figure 5. Data from the dust sensor.

Discussion

Arousal level

Although, not statistically significant, decrease of arousal was the most common response, seen in 6 subjects. All three possible responses were seen: increase, decrease, and same level of arousal. Those results contradict the findings of the 1974 study [3], which found almost universal and statistically significant increase in arousal. The differences between the studies were numerous: the previous study was conducted in the lab conditions, using more sensitive finger electrodes, and the subjects received significantly higher amount of nicotine. Also,

all subjects were regular smokers, who abstained from smoking for 8 hours before the experiment.

Another explanation for the discrepancy could be bad EDA data quality in our experiment. The data in the Figure 6 shows sudden falls and raises of the EDA signal, and a lot of the time EDA readings were zero. Similar data was seen in other subjects. Although, this could be attributed to physiology, more likely explanation is a problem with the Q-sensor. We validated that the Q-sensors worked properly when they were received. Unfortunately, Q-sensors were not validated right before the experiments because they appeared to work fine beforehand. Afterwards, we found that an electrode was loose in one Q-sensor. As a result it was not making the connection without applying pressure. This could be a possible explanation for sudden drops in the EDA signal.

Regular versus occasional smokers

The effect of smoking on EDA could be very different in regular and occasional smokers. This is an observational conclusion and it is not backed up by any statistics. Occasional smokers seemed to have noticeable arousal during onset of smoking, as seen in Figure 7. This was not observed in regular smokers; they seemed to have more consistent EDA before, during and after smoking. It is possible that occasional smokers get aroused before smoking because they are nervous or they anticipate the rewards of smoking. Regular smokers are quite used to nicotine and they are not aroused by the prospect of smoking one cigarette.

It is possible that EDA monitoring would be most useful for occasional smokers, and could possibly detect the desire to smoke, even before the action occurred.

Temperature and accelerometer

We did not perform statistical analysis on the temperature and accelerometer data, but observationally we noticed patterns during smoking. Those patterns could be seen in Figure 6. The temperature tended to decrease when subjects were smoking, because they went outside where it was much colder. Also, accelerometer data had a distinct pattern associated with the arm movement when smoking. Potentially, temperature and accelerometer data could be used as an aid in differentiating smoking events.



Figure 6. Sample data from one subject, showing EDA, accelerometer and temperature.



Figure 7. Raw data from an occasional smoker (top), and a regular smoker (bottom)

Dust sensor

The increase in dust sensor's output is clearly seen during smoking, even when the subject was standing outside in the wind. We noticed that the sensor readings were not increasing during smoke inhalation. The subject did not blow the smoke on his hand when smoking, but tended to move the hand down to the waist after inhalation. More often, the sensor readings increased when the cigarette was down at the waist level. In that position, the smoke seemed to envelop around the wrist and the sensor. The sensitivity of the dust sensor could be further improved by changing its orientation. The hole for the dust was facing away from the wrist, which meant it was usually perpendicular to the smoke. Such orientation makes the sensor less sensitive to the smoke.

By reducing the size of the dust sensor, it could become a very attractive option of smoking detection. Unfortunately, the dust sensor could trigger a false alarm when the wearer is subjected to secondhand smoke, since the sensor cannot distinguish from an external smoke source. If a sensor such as accelerometer is added, data from the dust sensor could be correlated to the wearer's activity of the hand, and thus greatly increase the accuracy.

Conclusion

We measured the effect of smoking on the EDA in the "wild". We did not see any statistically significant trends in the EDA during smoking, but we saw that decrease of arousal was the most common response. We constructed and tested dust sensor, and showed that it could be promising to use in the detection of smoking behavior.

Bibliography

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