DEMONS: An Integrated Framework for Examining Associations between Physiology and Self-Reported Affect Tied to Depressive Symptoms

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Abstract

Depression is a prevalent and debilitating disorder among college students. Advances in mobile technology afford the opportunity to collect heterogeneous data while people are in their natural settings. The aim of the current paper is to propose an integrated framework, DEMONS (DEpression MONitoring Study), for combining passive and active data sources using a wearable sensor and a smartphone application. The ability to combine passive and active longitudinal data with mobile devices allows for better understanding of the temporal relations between self-reported affect and physiological variables (e.g., heart rate variability) linked to depressive symptoms. Adoption of the proposed framework will provide crucial information regarding the development and maintenance of depression in college students, as well as increased opportunities for early detection and intervention.

Author Keywords

depression, smartphone sensing, mobile health, ecological momentary assessment

ACM Classification Keywords

J.3 [Life and Medical Sciences]: Health; J.4 [Social and Behavioral Sciences]: Psychology

Introduction

According to the American College Health Association, 33 percent of college students felt "too depressed to function properly" at least once in 2014. Given the academic consequences, impact on social functioning, and increased risk of suicide associated with depression, it is critical that we identify increasing depressive symptoms rapidly. However, symptoms of a Major Depressive Episode are typically only assessed via self-report in traditional clinical settings, which requires the individual to elect to undergo an evaluation.

Independent lines of research have found reliable self-report (e.g., negative affect; [8]) and physiological markers (e.g., reduced heart rate variability (HRV) and skin conductance (GSR); [4]) of depression. Modern mobile technology allows researchers and clinicians to examine how affect and physiological variables unfold and interact. However, there have been few efforts to link self-report and physiological markers using mobile technology despite the value of convergent approaches to more reliably identify individuals at risk. Mental health professionals perform little better than chance at predicting a range of important clinically relevant outcomes, such as suicide and depression relapse. There is thus a clear need to better understand how depressive symptoms manifest in the daily lives of college students, so that more precise prediction models can be developed.

The purpose of this research is to demonstrate the feasibility of DEMONS, an integrated active and passive data collection framework, by examining self-reported negative affect in relation to HRV and GSR trajectories. Repeated assessments of affect were administered via personal smartphones multiple times per day. A stressful event was defined as an increase in self-reported negative affect that exceeded one standard deviation of the participant's normal reporting habits. HRV and GSR were sensed every minute via a wrist sensor. An integrated framework will allow researchers to address emerging issues in depression research. For example, despite theoretical expectations that changes in subjective distress would closely track changes in physiological indices, observing desynchrony across indicators is not unusual in the lab. The proposed framework will allow researchers to better understand how the interacting nature of self-reported negative affect and physiological markers changes across time and in unique ways for those experiencing or at risk for depression. Ultimately, this collaborative effort between clinical psychology and engineering researchers can lead to enhanced and earlier detection of depression onset and recurrence in college settings by modeling real-time fluctuations in affect and physiological markers in people's natural settings. This system could also be adapted to automatically trigger personalized interventions for individuals when notable increases in negative affect are sensed (e.g., encouraging someone to use reappraisal or other emotion regulation strategies when they have a spike in distress).

Related Work

Although depression research has traditionally relied on laboratory-based approaches, advances in mobile and smartphone technology have made it possible to monitor how emotional, psychological and physiological systems interact in the course of daily life [6, 7, 1, 3].

Reality, an application developed by Eagle and Pentland *et al.* [2] was used to investigate relationships between the structure of social networks and mobility patterns. The StudentLife study [7] used a smartphone app to passively and actively monitor students over the course of a semester. Researchers identified a strong correlation between sensing data and PHQ-9 depression scores. Another app, Purple Robot, was used to assess depression by detecting location, movement, and phone usage [6]. In [6, 7, 1, 3], the authors also used mobile GPS data to explore correlations between mental health status and mobility patterns.

Active and Passive Monitoring Framework

The DEMONS framework is shown in Figure 1. The framework allows researchers to design and conduct a study without any software development experience. It employs Sensus, a mobile crowdsensing application, in combination with the Basis Peak, a wrist-worn fitness tracking device. These technologies together allow the collection of smartphone sensor data, participant physiological data, and ecological momentary assessment (EMA) responses via surveys. This pairing can offer benefits to researchers by collecting heterogeneous data from real-world settings and thus allowing the investigation of new relationships.

Implementation of a research study using this framework takes place in two phases. First, researchers create a study sensing plan, called a protocol, using the Sensus application *Protocol Editor*. Researchers then share the protocol definition with study participants via email, all of whom have installed the app on their personal phones. Second, participants download the study protocol using the *Protocol Loader* and begin the *Sensus Mobile Runtime* execution. The application then collects passive sensor and active self-report data for the duration of the study transmitting the data periodically to cloud storage, while the Basis Peak collects physiological data.

Sensus

Sensus is an open-source, generalized, mobile crowdsensing platform available for Android and iOS. Many researchers lack the resources or software development expertise necessary to fund or create research-focused applications in an ad-hoc manner; Sensus avoids this obstacle and provides a flexible platform that can be tailored to the specifics of a particular study. All interaction with the application takes place via menus within its GUI. Sensus performs multiple primary functions, including accessing sensors, recording, saving and anonymizing readings, and transmitting data via cell networks or Wi-Fi to cloud storage. As mentioned above, Sensus is organized around sensing plans called protocols. Protocols consist of probes, which collect passive data and may be selected from available sensors on the host device, and surveys, which may be scheduled to appear at random or at specific times. Protocols are stored in encrypted JSON files and then shared between devices.

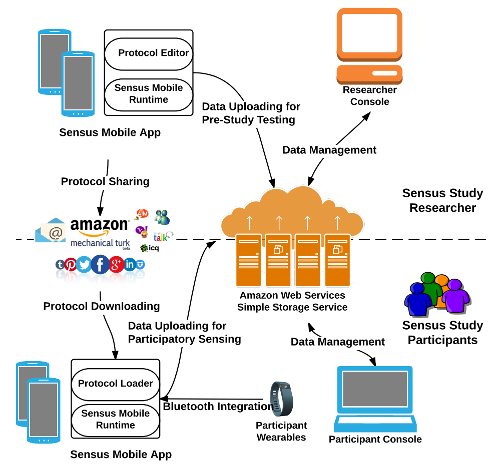

Figure 1: The DEMONS framework.

Wearable Sensors

For this study, we utilize a Basis Peak watch capable of recording heart rate, galvanic skin conductance, and other metrics. This device is primarily marketed as a fitness tracker and was chosen for this study because of its long battery life and biological sensing capabilities. Participants were told that the watch would monitor some of their physiological variables but were not given detailed information about watch features. They were asked to wear the watch during their waking hours and charge it overnight.

DEMONS Case Study

We conducted a study using the DEMONS framework to examine the associations between physiology and self-reported affect and depressive symptoms. Fifteen college students with Android smartphones were recruited to complete the 7-item Depression subscale of the Depression, Anxiety and Stress Scale (DASS-21 [5]) during the pre-screening assessment conducted at the beginning of the semester. In addition to downloading Sensus on their smartphone, each participant wore a Basis Peak smartwatch that recorded heart rate and skin conductance averaged over 1 minute intervals.

Participants reported their levels of negative affect up to 6 times per day. All observations were time stamped, allowing for matching with the corresponding physiological data. Preliminary data analysis indicated that only seven participants had usable data due to a variety of factors, including low EMA firing (attributable to software bugs) and participant response rate, as well as participant noncompliance with wearing the smart watch.

We present these pilot data as a proof-of-concept that this approach can effectively combine active and passive data sources. Analyses addressed the temporal relationship between HRV, skin conductance, and self-reported negative affect. We focused on instances in which there was an increase in negative affect greater than one standard deviation from a participant's average. Spikes in negative affect were isolated and correlated with physiological data spanning the hours immediately before and after the spike. Heart rate and skin conductance metrics were averaged over ten minute spans and plotted for a comparison of general trends. As seen in Figure 2, the proposed framework allows for examination of temporal relations among depression levels, skin conductance, and HRV, allowing for observation of patterns and trends adjusting for depression level. Trends in GSR and HRV trajectories can be obtained for stressful events and for different levels of depression, providing a detailed view of the interplay between these factors.

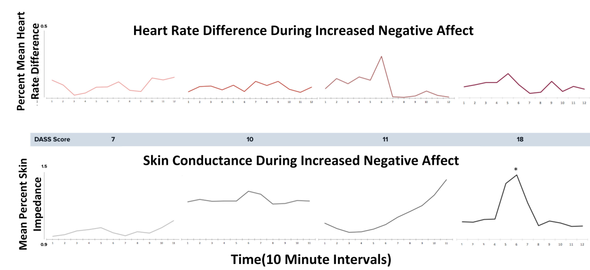

Figure 2: For different levels of depression, heart rate and skin conductance trajectories in relation to spikes in self-reported negative affect (above 1 SD from individual mean).

This study only examined data from 7 participants. A larger sample size is needed to make valid inferences from the data. Issues related to Sensus' compatibility with certain smartphone models and participant noncompliance in wearing the Basis Peak were also present. Funnel interviews containing participant feedback are currently being reviewed for clues to improve adherence.

Conclusions

Current methods used to monitor depression are typically based on retrospective self-report with little data to contextualize subjective experiences. These rely on client motivation to seek out assessment and only small numbers of people can be monitored. The proposed framework integrates actively and passively sensed data in order to understand the temporal dynamics of self-reported mood as it relates to trajectories in physiological markers found in depression. Importantly, this approach can be applied broadly; for example, to monitor anxiety and eating disorders. The proposed framework will enable researchers and clinicians to better understand the links between changes in emotion, stressors, and physiology to optimize models of prediction and, ultimately, intervention.

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