Let Me Relax: Toward Automated Sedentary State Recognition and Ubiquitous Mental Wellness Solutions

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ABSTRACT

Advances in ubiquitous computing technology improve workplace productivity, reduce physical exertion, but ultimately result in a sedentary work style. Sedentary behavior is associated with an increased risk of stress, obesity, and other health complications. *Let Me Relax* is a fully automated sedentary-state recognition framework using a smartwatch and smartphone, which encourages mental wellness through interventions in the form of simple relaxation techniques.

The system was evaluated through a comparative user study of 22 participants split into a test and a control group. An analysis of NASA Task Load Index pre- and post- study survey revealed that test subjects who followed relaxation methods, showed a trend of both increased activity as well as reduced mental stress. Reduced mental stress was found even in those test subjects that had increased inactivity. These results suggest that repeated interventions, driven by an intelligent activity recognition system, is an effective strategy for promoting healthy habits, which reduce stress, anxiety, and other health risks associated with sedentary workplaces.

Categories and Subject Descriptors

H.1.2 [**Information Systems**]: User/Machine Systems—*human factors, Human information processing.*

General Terms

Algorithms, Design, Human Factors.

Keywords

Personal Health Assistant, Sedentary State Recognition, Intervention Techniques, Stress, Anxiety, Cognitive Reappraisal, Mental Wellness, Ubiquitous Computing

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1. INTRODUCTION

The National Institute of Occupational Safety Health has published a number of studies examining the effect of job stress on employee health [25, 22]. Their findings indicate approximately 40% of working adults find their workplace extremely stressful [26]. These high stress conditions lead to stress related disorders, resulting in an annual health care cost in excess of $42 billion in the United States alone. The link between stress and health care costs are well documented. Less clear, however, are stress related non-health care costs to the employer and the larger economy [14]. It is estimated that employee stress leads to a loss of $150 billion annually in lost productivity, absenteeism, poor decision-making, stress-related mental illnesses, and substance abuse or other high risk behavior [10].

Center for disease control and prevention defines sedentary lifestyle as, "no leisure-time physical activity, or activities done for less than 20 minutes or fewer than 3 times per week" [16]. Studies indicate that sedentary jobs have high risk factors for many physical and mental health conditions including stress, obesity, and high risk behavior [6, 23]. Hence, our study focuses on environmental factors and jobs, the nature of which promote sedentary behavior or low physical exertion. In addition, there is clear evidence that "development of methodologies to prompt individuals with personalized health-promotion strategies based on spatio-temporal health context" will improve both physical and mental health (thus this work furthers Goal 6 of [7]). Although existing solutions focus primarily on motivating users to exercise, they have little success in cases where users already exhibit other healthy behaviors. On the contrary, they have been largely unsuccessful with the majority of the users because most people eventually resort back to habitual unhealthy behavior.

Our proposed solution is *Let Me Relax*, a ubiquitous computing system, which integrates smartwatch and a smartphone technology to intelligently deliver timely interventions in the form of notifications to the user. Using notifications, the system suggests a relaxation exercise chosen from a set of preconfigured techniques suitable for workplace environments. The duration between relaxation prompts and the duration of exercises can be customized to user preferences. The system includes a smartwatch application (Let Me Relax), which connects to an android application (Let Me Relax) on the user's smartphone. The smartphone application tracks user activities by analysing accelerometer data, streamed from the companion smartwatch application. Following this approach we establish the following hypotheses:

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1. Our intervention approach will improve overall employee health, productivity, and organizational effectiveness.

2. Integrating short bursts of relaxation and simple physical exercises through notifications and instructions driven by intelligent wearable devices will, over time, lead to an outsourcing of healthy behavioral controls[27] to the context of their personal workspace. Thereby, existing outsourced behavioural control (sedentary work environment), hitherto triggering negative sedentary behavior, is gradually redefined and mapped to more healthy active behavior.

3. The resulting changes incorporating healthier, more active behavior in sedentary work environments will, over time, become habitual.

2. PRIOR WORK

Wearable sensor applications encourage healthy living [3, 21] by monitoring user activity, capturing fitness related metrics, and providing exercise suggestions to improve health outcomes. Wearable sensors capture and record physiological variables including heart rate and heart rate variability, blood oxygen level, skin conductance, etc. Technological advancements in wearable sensors to encourage users to take regular breaks to reduce the negative effects of sedentary behaviour are increasingly adopted. Ubiquitous systems for fitness tracking tend to share common goals of *Let Me Relax*, and they can be classified across three categories.

2.0.1 Automated systems for physical health

Automated systems for better physical health, track user sedentary state, and generate appropriate physical activity reminders based on demographics and contextual details. *Step Up Life* [21] is a context aware health assistant smartphone application that generates contextually suitable physical exercise reminders on identifying a prolonged sedentary state. The exercise suggestions are physically intensive that mostly suit a young, health conscious demographic, and are not appropriate for the common unfit sedentary user.
Move[1], an iOS application, similar to *Let Me Relax*, focuses on the workplace. However *Move* only generates physical activity reminders, and users explicitly set reminders. *Fitbit*[2], an advanced fitness tracking system tracks step count, calories burnt, and sleep duration. However, *Fitbit* is akin to a fitness tracking device, which does not intrinsically motivate physical and mental wellness. Automated fitness tracking devices, despite considerable acceptance by health conscious users, have little impact among office demographics. Additionally, these systems have a narrow scope as the suggestions are limited to activity reminders, rather a larger scope of supporting cognitive reappraisal and mental wellness.

2.0.2 Manual systems for mental wellness

Mobile phone based intervention techniques for mental wellness and relaxation are not new, but such techniques are still in infancy [8]. There are a few mobile based applications, which incorporate cognitive and behavioral methods and exercises to ameliorate mental wellness and mitigate work related stress [1, 2].

[1]goo.gl/y66Fkv
[2]goo.gl/Pwe9Pi

Ovia [2] is a mobile phone application that uses acceptance and commitment therapy (ACT). *Ovia* users learn skills that prepare them to take corrective actions toward maintaining better mental wellness. Despite its wider scope of understanding user stress, life satisfaction, and psychological flexibility *Ovia* lacks intelligence, and is heavily dependent on active user involvement. *Mobilize* [4] is an ecological momentary intervention and context-sensing system for depression. The system comprises of a smartphone application and a website for learning moods, emotions, cognitive or motivational states, activities, and environmental and social contexts of the user based on smartphone sensor data. In addition, *Mobilize* demands extensive user participation for validation of mood predictions and for learning reinforcement methods for depression by visiting a companion website. In addition to the mental wellness systems discussed thus far, we learn that stress-management interventions at the workplace can have an extensive impact on mental health [12]; community attitudes toward the appropriation of smartphones for mental health monitoring and self-management are positive provided that privacy concerns are addressed [20].

2.0.3 Automated systems for mental wellness

Relaxation techniques for mental wellness are well realized through ubiquitous systems. However, these systems demand conscious and continuous user input. The user presets the timing interval between breaks; notifications are blindly generated irrespective of the level of user activity.

Applying machine intelligence techniques to automate systems that support mental wellness and cognitive reappraisal to become independent of user input are currently underdeveloped. *Let Me Relax* takes a step toward applying machine intelligence by constantly tracking user activity and providing intelligent data driven notifications when prolonged sedentary behavior is detected. Hence, *Let Me Relax* serves three purposes, 1) Unlike other systems, a user is not notified though when physically active, 2) Unobtrusiveness, 3) Consistent with system goal to encourage relaxation after a prolonged period of inactivity.

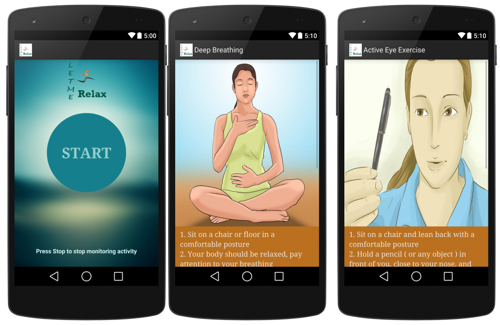
All fitness tracking systems discussed above strive to support better physical health, self regulation, mental wellness, cognitive reappraisal, and reduce stress. A very common functioning model among all these systems is that prompts are generated either at random intervals or scheduled by the user. Existing systems are not smart enough to automatically trigger prompts by assessing changes in a user's mood, physical state, or activity. This makes such systems heavily relay on the user inputs. Furthermore, the notifications are not specifically tailored toward workplace settings. *Let Me Relax*, addresses these shortcomings by intelligently generating notifications based on user inactivity; notifications are designed specifically for the workplace environment.

3. SYSTEM ARCHITECTURE

Let Me Relax, a ubiquitous system to cultivate the habit of taking a short break following a prolonged sedentary period, comprises of two subsystems: 1) Pebble smartwatch companion application, 2) Android smartphone application. *Let Me Relax* smartwatch application is built on Pebble

(a) (b) (c)

Figure 1: *Let Me Relax* pebble watch application states: (a) Home (b) Activity Tracking (c) Notification



(a) (b) (c)

Figure 2: *Let Me Relax* android application states: (a) Home (b) Deep breathing, (c) Active eye exercise.
Image credit: wikihow.com

watchapp SDK[3]; it runs on a pebble smartwatch[4]. The smartphone application is built on the Android platform, and it is compatible with smartphones running android version KitKat and above. User activity recognition is central to the functioning of *Let Me Relax*. Accelerometer data corresponding to a user's activity is streamed from smartwatch to smartphone for activity recognition. Both smartwatch and smartphone applications will be referred to as *Let Me Relax* for convenience. They work in conjunction to automatically identify a prolonged sedentary state, and unobtrusively notify the user to relax along with a suggestion. Thereby, the system aims at assisting users in achieving mental wellness, cognitive reappraisal, and relief from stress and anxiety.

3.1 Pebble Smartwatch Companion Application

Let Me Relax smartwatch application is responsible for two main functions: 1) Stream accelerometer data from pebble to a smartphone, 2) Notify the user along with associated messages through haptic feedback. The primary application interfaces of the pebble companion watchapp are shown in Figure 1a through 1c.

3.1.1 Stream Accelerometer Data to Smartphone

The Pebble SDK provides AppMessage APIs[3] that facilitate communication between a pebble watchapp and a smartphone application over push-oriented messaging protocol. The accelerometer data stream from pebble is bundled into a Dictionary data structure[3] that supports data serialization. The implementation of *Let Me Relax* is designed to handle four samples for each accelerometer data update; each sample comprises of x, y, z values.

3.1.2 User Notifications Through Haptics

Let Me Relax leverages Vibes APIs[3] to control embedded vibration motors. All notifications from the watchapp are encoded into three kinds of haptic feedback: 1) Short Pulse, 2) Long Pulse, and 3) Double Pulse. A short pulse acknowledges user selections like snooze or cancellation of a notification. A Long Pulse notifies a user to take a break and relax, after a prolonged period of inactivity. Lastly, a double pulse notifies the user the end of a relaxation period. Each notification from phone is pushed to *Let Me Relax* watch app over AppMessage infrastructure. Each message is exchanged as a dictionary object that bundles a tuple; each tuple represents a command and is given a unique number. Finally, the user is notified through a haptic feedback [17, 18, 19] based on the command encoded in the dictionary.

3.2 Let Me Relax - Smartphone Application

Let Me Relax is a smartphone application developed on the Android platform; it pairs with a companion smartwatch application running on a pebble smartwatch. The mobile phone application has three main components: 1) Pebble Connectivity Module, 2) Application UI, and 3) Background Services.

3.2.1 Pebble Connectivity Module

PebbleKit Android[5], a java library, provides a framework for an android application to communicate with pebble smartwatch. *Let Me Relax* leverages Pebble Kit Android to achieve five functionalities: 1) Launch smartwatch companion application, 2) Query pebble connection status, 3) Receive accelerometer data, 4) Exchange messages to acknowledge data reception, and 5) Send notifications to pebble.

3.2.2 Application UI

The user interface of *Let Me Relax* follows the standard UI design principles of Android[6]. The application *Home* screen, shown in Figure 2a, enables a user to initiate or stop activity tracking with a single button click. Furthermore, a user can create a profile through *Profile* screen; through *Settings* screen a user is allowed to set the duration after which a notification for relaxation is delivered, if the user is found sedentary. In addition, through the settings interface a user can also set the length of the relaxation period.

3.2.3 Background Services

Accelerometer data transfer from Pebble to smartphone, and classification of data to recognize user activity is a continuous process, while the application is active. *Let Me Relax* achieves this by implementing a data receiver, activity classifier, and a timer service on Android's service framework. An Android service can perform long running opera-

[3]Pebble SDK - developer.getpebble.com
[4]getpebble.com

[5]developer.getpebble.com/guides/mobile-apps/android/
[6]developer.android.com /guide/topics/ui/index.html

Table 1: Sedentary, Non sedentary confusion matrix

	Non Sedentary	**Sedentary**
Non Sedentary	96.02%	3.97%
Sedentary	5.09%	94.90%

Table 2: Activity share in an eight hour window

Activity	**Percentage**
Sedentary	67.46%
Non Sedentary	32.54%

tions in the background even when the user interface of an application is invisible or completely destroyed.

3.3 Activity Recognition

Let Me Relax implements a user independent activity recognition algorithm [15] to recognize sedentary and non sedentary states using the accelerometer data from a Pebble smartwatch. The application uses the KNN classification algorithm from the WEKA machine learning suite[7] with value of K set to ten. In addition, *Let Me Relax* implements the *Classify-Discard* method to avoid overgrowing accelerometer data file size, and to speedup the activity recognition process.

The training data set for the KNN classifier is built with approximately 2000 accelerometer data samples (1 sample - x,y,z data points) for each of the 6 common activities: Walking, Running, Jogging, Sitting, Jumping Jacks, and Stretching. Furthermore we consider activities, and associated data samples for Walking, Running, Jogging, Jumping Jacks, and Stretching as non sedentary states. A confusion matrix from 10 fold cross validation of labelled data samples with nearly 10,000 samples for each sedentary and non sedentary states (total 21,466 samples) is shown in Table 1. The classification accuracy is 95.444%, with an F-measure value of 0.953 for non sedentary state and 0.956 for sedentary state.

To validate classification accuracy by subjective feedback, we recorded classification results for each minute for two users during the user study. The two users, with an average age of 25 years, worked at a software firm as interns; their work day was mostly sedentary, although they were relatively active for such a job, with an hour of lunch break out of 8 working hours. The share of sedentary and non sedentary activities in an 8 hour window, aggregated for the two users, is shown in Table 2. The two users validated an inactivity level of 67.46% (~5.4/8 hours) reported by *Let Me Relax*.

4. RELAXATION THROUGH INTERVENTION

Richard S. Lazarus defines Stress as: "A condition or feeling experienced when a person perceives that demand exceed the personal and social resources the individual is able to mobilize" [11]. Furthermore, anxious and stressed people often decide that an event is dangerous, difficult, or painful, and they don't have the resources to cope[8]. Effects of stress on an individual highly depends on his/her perception; an event perceived as stressful by one person, can be a normal situation for the other. Interventions, in-terms of relaxation techniques, help to regulate stress on brain, as the brain interprets and translates complex changes in the environment and body and determines when to turn on the "emergency response." *Let Me Relax* implements twelve relaxation methods that are widely used in self-regulation and stress reduction therapy and are empirically proven to help people relax by disengaging from the current context of work[8] [24]. In addition, the relaxation methods adopted by *Let Me Relax* do not require special equipments, are easy to learn, and highly customizable to the workplace environment.

[7]www.cs.waikato.ac.nz/ml/weka/

[8]mindtools.com

4.1 Relaxation Methods

Most relaxation methods implemented by *Let Me Relax* are simple physical exercises that can be performed while sitting at a desk. Though none of the suggested relaxation method includes laborious physical activity, Only some expect the user to stand or walk within the workplace. Relaxation methods implemented by *Let Me Relax* can be categorized into two groups: 1) Active Relaxation Methods, 2) Passive Relaxation Methods. While active relaxation methods demand conscious user involvement, passive relaxation methods are inconspicuous and do not require user attention. The rationale behind all relaxation methods is to disengage a user from current context of work, and provide some time for self-regulation and cognitive re-appraisal. For each relaxation method suggested, the user is presented with a set of instructions along with a demonstrative image. For example, Figure 2b and Figure 2c assist a user in performing deep breathing and active eye exercises respectively.

4.1.1 Active Relaxation Methods

Let Me Relax suggests a total of ten active relaxation methods: 1) Body Scan Meditation, 2) Active Eye Exercise, 3) Passive Eye Exercise, 4) Natural Breathing, 5) Deep Breathing, 6) Neck and Head Rolls, 7) Shoulder Exercise, 8) Back Stretch, 9) Leg Stretch, and 10) Drink Water.

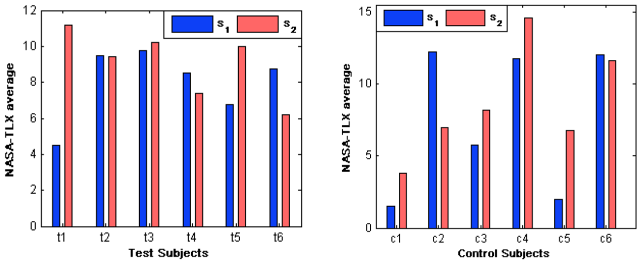
4.1.2 Passive Relaxation Methods

Unlike Active Relaxation methods, Passive Relaxation methods do not require active user involvement and efforts as they reside on the periphery of a user's attention. *Let Me Relax* suggests two passive relaxation methods: 1) Listening to Music, and 2) Watching Video.

5. EXPERIMENTS

We designed a user study to evaluate the efficacy of *Let Me Relax* in reducing negative effects of sedentary behavior at work place. For this study, we recruited 22 participants (19 male, 3 female) with ages ranging between 21 and 54 ($\mu_{age} = 32$). Data from 10 participants were excluded because they either did not follow experimental protocol or sensor data were corrupted during the experiment. The pool of subjects consists of students working part-time as teaching assistants or research assistants, and university staff with various responsibilities. Using a diverse group of participants combining sedentary and non-sedentary working environments improves our understanding of the system and its effectiveness under varying conditions.

In our experiments, we divided participants into two groups: a test group and a control group. Each participant in both groups was outfitted with a Pebble smartwatch and provided with an $Android^{TM}$ smartphone or portable tablet device. The experimental protocol consists of a pre and post



(a) (b)

Figure 3: NASA-TLX response: (a) Subjects in test group (b) Subjects in control group.

work stress evaluation questionnaire using the NASA Task Load Index (NASA-TLX). The NASA-TLX is a widely-used, subjective, multidimensional assessment tool that rates perceived mental workload in order to assess a task, system, or team's effectiveness or other aspects of performance [9]. As a subjective measure of mental workload, we use NASA-TLX to get an approximate index of overall stress level [5]. Each participant is asked to complete the NASA-TLX questionnaire at the beginning of the experiment to assess their individual baseline. They are also instructed to complete a second questionnaire at the conclusion of their work day.

The experiment encompasses a full workday, usually 9am. to 5pm. with a few deviations. Over the course of the day, the system monitors sedentary behavior and sends a notification to the participant if s/he is found to have been sedentary over a pre-specified duration of time (60 minutes). Participants in the test group are notified to perform one of the tasks enumerated in Section 4.1, while participants in the control group are not asked to perform any tasks.

6. RESULTS

6.1 Subjective Measures of Workplace Stress

To test the effect of the *Let Me Relax* system on workplace stress, we calculated the initial mental stress level at the beginning of the work day, s_1, as estimated using subjective measures obtained from the NASA-TLX questionnaire, and mental stress levels at the end of the work day, s_2, for both control and test groups. Figure 3 illustrates s_1 and s_2 for both groups. As illustrated in Figure 4, we quantify the difference between the two groups, computed as the average change in stress level (Δ_s) for each group as a fraction of the original stress level at the beginning of the experiment using the following formula:

$$\mu_{\Delta_s} = {}^1/_n \sum_{i=1}^{n} \frac{s_2 - s_1}{s_1} \tag{1}$$

6.2 Inactivity and Workplace Stress

Prolonged sedentary behavior at work has a negative impact on mental stress as measured through heart rate variability (HRV) [13]. For the purpose of our analysis, we use an aggregate measurement of sedentary behavior. In this metric, inactivity, is calculated over a pre-specified time block (60 minutes) as described in Section 5. We estimate the level of inactivity as the percentage of time blocks where

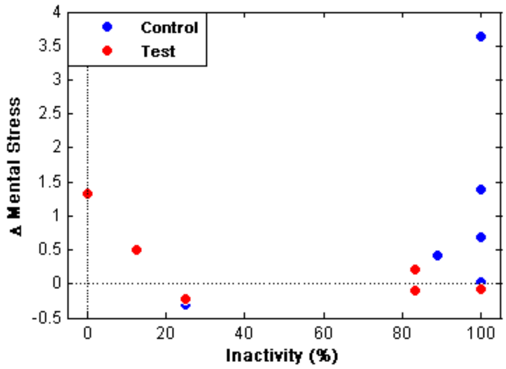


Figure 4: Inactivity and changes in subjective measures of mental stress

the participant is found to be sedentary. Figure 4 illustrates inactivity and changes in subjective measures of mental stress for control (blue) and test (red) populations.

7. DISCUSSION

The sedentary nature of the workplace acts as an environmental control factor, which serves to trigger sedentary behavior. Our intervention uses short bursts of relaxation and simple physical exercises through notifications and instructions driven by intelligent wearable devices as new triggers of healthy behavioral controls. We evaluated our system using a comparison study composed of 6 test and 6 control subjects. Users in the test group were exposed to system generated notifications for relaxation and exercises whenever the user was found sedentary. Alternatively, the control group were not exposed to system notifications of any kind. However, the system tracked and recorded their activities throughout the day.

In Figure 4, we observe that on average, control subjects were more inactive than their test counterparts. Figure 4 also shows a trend of reduced mental stress, even with increased inactivity, among the test group. This trend is expected because the *Let Me Relax* system is designed to intervene where there is sedentary behavior. Therefore, with increased sedentary behavior (i.e., increased inactivity), we expect to see reduced mental stress in test subjects.

8. CONCLUSIONS AND FUTURE WORK

In this work, we have designed and tested the functionality of *Let Me Relax*: a fully automated sedentary-state recognition framework that encourages mental wellness through interventions in the form of simple relaxation techniques. *Let Me Relax* is a ubiquitous computing system, which integrates a smartwatch and a smartphone to intelligently deliver notifications prompting the user to engage in relaxation exercises. These interventions serve to improve overall employee health, thereby improving employee productivity and organizational effectiveness. We conducted a field study to test the efficacy of *Let Me Relax* at reducing sedentary behaviour and lowering mental stress in the workplace. Our preliminary results show consistent, though not significant, support to our hypothesis. However, further studies with a larger population are required to test for statistical significance. Work is underway to conduct a larger field study which will include an additional category of users who will serve as both test and control subjects on alternate days.

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