EasyBreathe: Chronic Stress Reduction Platform

Pascal Loose, Mark Zolotas, Charitos Charitou

***Abstract*—Chronic psychological stress is often associated with the prevalence of mental disorders in modern healthcare, such as heart attacks, panic attacks, and substance misuse. Severe mental conditions of this scale have approximately 75% probability of settling in adults by the age 24. An ideal method of preventing these manifestations is to therefore provide young adults with a mechanism for stress relief, thereby reducing the likelihood of these mental disorders surfacing in later life. To accomplish the feat of improving juvenile stress levels, we introduce EasyBreathe as a wearable stress reduction system that is composed of both an Apple Watch and an iPhone. A fundamental objective of this platform is early prediction of stress in users, which will be accomplished using machine learning techniques.**

I. Introduction

An increasing concern for modern healthcare is the prevalence of mental disorders and diminished wellbeing in response to high levels of psychological stress. Excessive amounts of stress over long-term periods of time have demonstrated correlations with a vast range of mental illnesses and severe medical conditions. For instance, studies have linked stress with strokes, heart attacks, anxiety disorders, depression [1], asthma [2], panic attacks [3], as well as smoking and other substance misuse [4][5]. Whilst most of these examples are likely related to traumatic individual experiences that have consequently induced post-traumatic stress disorder (PTSD), chronic stress generated through environmental, emotional, and other factors also indicate strong links with the aforementioned conditions.

Mental illnesses of this scale are leading causes of disability in young adults [6] and approximately 75% of these disorders have their onset by age 24 [7]. Therefore, an ideal method of tackling these conditions via healthcare is to identify and prevent their negative effects prior to diagnosis. As stress has a critical influence over the onset of these disorders, reducing and managing extreme levels of juvenile stress fits the criteria for improvement in overall mental wellbeing of the general population.

To accomplish this feat, we aim to design a wearable system for assisting users in reducing persistent states of stress. Wireless healthcare is an innovative practice whereby expert medical diagnosis and feedback may be provided to patients on a real-time basis through a portable and robust system. Furthermore, machine learning (ML) techniques are a growing trend in the field of personalised medicine, with increasing application in the domain of mobile healthcare. As a result, our research project aims to employ EasyBreathe, a chronic stress reduction system that will apply these principles in order to assist young adults in stabilising their irregular stress levels. This platform will incorporate two fundamental components into its design, an Apple Watch for monitoring and calming purposes, as well as an iPhone application for data analysis.

In this design report, we introduce a generic model for chronic stress reduction through the aid of our proposed EasyBreathe platform. Section II details a set of research hypotheses to test against this system upon completion, as a method of experimentally validating the performance of EasyBreathe on the mental state of Imperial College students. Following this, Section III provides a background of related work and similar systems. From a holistic design perspective, Section IV describes the targeted platform in terms of its electronic and software mechanisms. Finally, an evaluation plan is discussed in Section V and conclusive remarks about the EasyBreathe project are provided in Section VI.

II. Research Hypotheses

By exposing Imperial College students to the EasyBreathe platform under a racing car simulation setting that induces elevated stress levels, we assert the potential benefits of this system's stress reduction functionality through the following hypotheses:

(a) Setting a slow and controlled breathing pace via a rhythmic interface will incite relaxed emotional states in participants at a faster rate than without any intervention post-simulation.
(b) Playing self-selected or classical music will incite relaxed emotional states in participants at a faster rate than without any intervention post-simulation.
(c) Providing reassuring messages and offering conversational advice will incite relaxed emotional states in participants at a faster rate than without any intervention post-simulation.

III. Related Work

A core feature of EasyBreathe is accurate and seamless estimation of psychological stress in tested users, for which there are various techniques ranging from objective measurements of physiological signals in patients, to conducting surveys for a perceived stress evaluation. In Vrijkotte's study [8], work stress in subjects was monitored continuously using ambulatory instruments for blood pressure (BP) and heart rate (HR) readings. The results indicated that higher HR and BP variability correlated with detrimental work stress levels. Poh et al. [9] instead attached a wearable sensor to participants and their electrodermal activity (EDA) was assessed as they performed mental and physical exercises. Their findings suggested a dramatic increase in skin conductance levels following both mentally and physically straining experiments. From a survey-based approach, the Perceived Stress Scale (PSS) is a well-known instrument [10] used to measure the degree of an individual's appraisal of stress during different situations.

For quantitative and precise psychological stress evaluation through a wearable device, EasyBreathe will rely on a combination of physiological variables, such as HR variability (HRV), skin conductance, and body movement. HRV analysis is a measurement of intervals between successive heartbeats and is often used as a biomarker for stress assessment [11]. This analysis can be commonly achieved through photoplethysmography (PPG), an optical method of measuring blood oxygenation variations, which is currently available to the Apple Watch. However, Lu and Yang [12] presented a key limitation behind this technique by demonstrating the significant effect of motion artifacts on PPG waveforms. In order to offset the impact of physical activity on physiological quantities, a study by Wu et al. [13] used two modalities of sensors by integrating HRV sensors and accelerometers in predictive stress analysis. Their results demonstrated a significant correlation between accelerometer data and HRV readings for stress modelling.

There are various mindful and calming approaches to reducing high mental stress levels in a human being. A small-scale study [14] examining the effects of yoga on anxiety and stress of breast-cancer patients presented positive psychological responses after the participants implemented a recommended yoga regimen. The effectiveness of different types of music on emotional state and physiological arousal of college students was also explored in the Labbe et al. paper [15]. A mentally demanding test was first administered to the students to raise their stress levels and then they would either sit in silence or listen to music for 20 minutes. Following this experiment, the results signified substantial reductions in anxiety and positive increases in states of relaxation after exposing subjects to self-selected and classical music, in comparison to sitting in silence or listening to heavy metal music.

In contrast, there are also numerous approaches for inducing stress in human beings. Brouwer and Hogervorst designed a Sing-a-Song Stress Test (SSST) [16] for participants to complete, whereby contestants had to sing a song aloud at sudden notice during the test. Results of this experiment demonstrated elevated HR and skin conductance levels in the one-minute interval following singing. Similarly, Kirschbaum et al. introduced the Trier Social Stress Test (TSST) [17] as a method for inducing psychological stress in an experimental setting. This test required human subjects to present a speech and perform mental arithmetic in front of an audience within a 10-minute test period. Each participant encountered substantial increases in stress responses.

A competitive selection of ML algorithms is currently available for stress recognition in research applications similar to EasyBreathe. Karstoft et al [18][19] investigated capabilities of predicting PTSD tendencies in pre-deployed soldiers through use of ML methods. They applied a feature selection algorithm for identifying the most predictive variables of PTS and used Support Vector Machines (SVMs) [20] for classification of individuals into groups of resilience or distress. SVMs are a state-of-the-art supervised learning algorithm for classification problems and have been broadly applied in stress classification by using modified techniques [21][22], or by integrating with other algorithms in order to form a hybrid system [23]. Other classifiers have also been extensively used in stress recognition, such as the Naïve Bayes and Decision Tree classifiers [24]. With regard to feature extraction from stress-related sensor data, signal processing algorithms involving time or frequency analysis of the incoming signal are commonly employed methodologies [13][24].

Similar systems to EasyBreathe are currently available in the mobile healthcare application market. For example, Calm [25] is a Watch app undergoing development with the aim of performing real-time stress detection and providing breathing exercises for patients to follow as a method of calming. Similarly, Headspace [26] applies meditation techniques through a Watch and iPhone, allowing users to perform mindfulness exercises according to this system's guidance. Other Watch application approaches have taken more drastic measures for stress relief, such as Voodoo Stress Relief [27], which manages stress levels of the user by offering them a game interface to exert pain on an artificial voodoo doll.

IV. EasyBreathe System Design

A. System Overview: Hardware

The EasyBreathe platform can be decomposed into a few major software and hardware components, which are displayed in Figure 1. First and foremost, the two key electronic wearable devices acting as the core of EasyBreathe are an Apple Watch for recording stress-related patient information, and an iPhone for performing data analysis over this continuous input stream. Aside from utilising the Apple Watch for monitoring purposes through in-built sensors, this device will also include an application to administer stress-relief treatment. The iPhone application will offer users the ability to register with this stress-reduction platform and store personal data. This daily feed of user data could then be directed towards a physician or doctor for expert diagnosis. Coupled with these two devices, the HealthKit tool will support the back end of our platform by providing storage services.

A wearable stress-relief application requires real-time physiological variable readings, most notable of which is HRV. The Apple Watch relies on PPG to estimate HRV and uses a sensor that is composed of light-emitting diodes (LEDs) and photodiodes. By pairing green LED lights with lightsensitive photodiodes, this device is able to detect the amount of blood flowing through a user's wrist at any given moment. For an increasing frequency of heartbeats, there will be greater green light absorption and likewise lower frequency will correspond to decreased absorption. These LED lights flash hundreds of times per second, enabling an Apple Watch to precisely pinpoint a user's HR on a minute-by-minute basis. Additionally, this sensor is designed to compensate for low signal levels by increasing both LED brightness and sampling rate [28].

B. System Overview: Software

From a software perspective, the design of EasyBreathe is divided into two segments: an iOS app to operate via the iPhone and a watchOS app for Apple Watch usability. In order to create this Watch app, an iOS app must first exist as a connection layer. The Watch app is then implemented as a separate target to the Xcode project and is built as a package

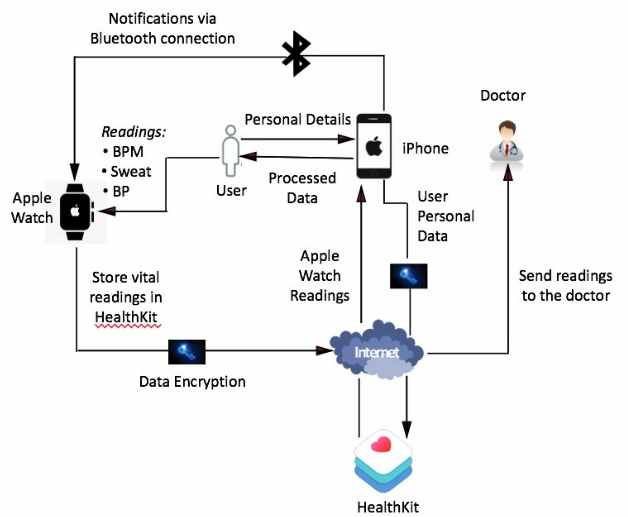

Fig. 1: EasyBreathe system architecture diagram consisting of hardware and software component interactions.

inside the iOS app bundle. This section of the report will focus on the integration of these two app structures.

WatchKit is the development framework provided by Apple specifically for Watch application development, and enables connection with existing iOS applications. This software kit consists of two bundles, a WatchKit Extension for the iPhone and a set of Watch interface features. In EasyBreathe, the Watch app will represent the main interface of our platform and is responsible for any user interaction, as well as for recording vital health parameters, such as beats per minute (BPM). Any collected data will then be transferred to the WatchKit Extension for further processing. WatchOS 2 is the OS version used throughout this project, as it has both of the aforementioned bundles installed and running locally. [29].

Apple's HealthKit is a generic method for apps and services to share health and fitness data openly with one another. For the EasyBreathe platform, HealthKit will primarily be used as the back end of our system, managing storage of patient-related information in secured locations. Personal details of the user and any monitored physiological variables, such as BP, will also be stored as encrypted data via this HealthKit tool.

With regard to the mobile application, the iPhone acts as the brain of our EasyBreathe platform. Data will be extracted from HealthKit and analysed through an iOS app. During this processing phase, stress-related information will be aggregated and fed into ML algorithms for accurate stress recognition results. Furthermore, historical data will be displayed through the interface of this application in a graphical form, allowing users to share this information with their doctor. Finally, in the situation of a user undergoing high psychological stress, the iPhone application will transmit a notification to the Apple Watch and a series of techniques will then be triggered in order to reduce these elevated stress levels.

V. Evaluation

A reliable and quantifiable experimental setting for evaluating the performance of EasyBreathe and the validity of our aforementioned hypotheses is introduced in this section. The following described experiment intends to stimulate stress in volunteers and thus present an opportunity in its aftermath to measure the effectiveness and efficiency of our solution in terms of stress relief. Throughout the experiment, participants will wear an Apple Watch that will record their vital signs.

The experiment will be conducted on the Imperial College campus, whereby volunteers will be selected at random from the student population and asked to drive a racing car simulation. Simultaneously, the participating students will perform a separate mental task by counting from 1200 backwards in 13 steps during the simulation test. This experiment forms an alternative of established methods, such as the Sing-a-Song Stress Test [16] or the Trier Social Stress Test [17]. Both of these research-based set-ups have proven to be effective in inducing stress by simulating a social scenario that results in raised stress levels, however replicating one of these would require time and resources. Furthermore, it would be difficult to incentivise volunteers to follow the actions described in these tests, while also potentially crossing ethical boundaries. As a result, we have selected a racing car simulation game as an engaging and feasible substitute.

During the experiment, patients will be wearing an Apple Watch device and will undergo a targeted dramatic increase in stress levels. This will increase multiple signals related to stress, most important of which will be HRV as measured in BPM. Throughout experimentation, we will make the following assumptions:

- Users will be in a relaxed state prior to initiating this experiment
- All users follow similar patterns in their vital signs when calming their emotional state of mind
- The duration for which volunteers enter a relaxed state post-experiment is homogeneous across all participants
- Users find highly reflexive game simulations under interview conditions relatively stressful
- A high stress level is attained once BPM increases by 20 from a volunteer's average reading, or exceeds a rate of 110 [30]

Before initiating this experiment, users will have their average HR measured using a provided Apple Watch. If any tasks related to driving a simulated racing car or performing a mental task increases the volunteer's HR significantly, then their wearable Watch will notify them through a small vibration. Our holistic solution will hence prove to be effective if it can measure HRV within a specific time range, detect substantial differences, and consequently notify a user through the Watch. The overall performance of EasyBreathe with regard to system design and operability will be evaluated by assessing the system according to this desired aim of accurately monitoring HRV. Other psychological variables will also be included in ML algorithms as a method of stress assessment, however HRV is the key metric of EasyBreathe.

In the aftermath of this experiment, there will be four different streams to test our hypotheses and compare results. The first stream will involve volunteers not using EasyBreathe at all, providing us with a measurement of how long it takes for these participants to naturally calm down. All the other streams involve students activating in-built functions of EasyBreathe. Each selected user will activate a single allocated function, which will either be the relaxing music player, the breathing rhythmic interface, or the interactive set of reassuring messages. At the end of this experiment, all results obtained from applying these different streams will determine how effective each EasyBreathe method is in comparison to a person naturally entering a relaxed state.

Finally, in order to receive subjective feedback regarding this platform on the whole, there will be a short survey provided to users. The questions included in this survey will cover usability, performance, and intuitiveness of our system. This survey will also reflect what the user thinks and perceives about the idea of using EasyBreathe on a daily basis.

VI. Conclusion

In conclusion, this design report highlighted our aim to build a chronic stress reduction platform, known as EasyBreathe. The primary objective of this system is to detect significant HRV and subsequently assist users in reducing stress by engaging them in stress-relieving exercises. A background research into current designs and methods that have achieved similar results has also been presented, with recognition of how our solution differs in terms of implementation. Finally, we outlined our planned process of experimentally validating our platform's performance and therefore asserting our hypotheses in this medical context.

References

[1] J. Herbert, *Fortnighly review. Stress, the brain, and mental illness*, BMJ: British Medical Journal 315.7107 (1997): 530.

[2] T. C. Theoharides, et al. *Contribution of stress to asthma worsening through mast cell activation*, Annals of Allergy, Asthma & Immunology 109.1 (2012): 14-19.

[3] S. A. Falsetti, H. S. Resnick, B.S. Dansky, R.B. Lydiard and D. G. Kilpatrick, (1995) *The relationship of stress to panic disorder: cause or effect. In C. M. Mazure, Does stress cause psychiatric illness?* (pp. 111147), Washington, DC: American Psychiatric Press.

[4] K. Lasser, J. W. Boyd, S. Woolhander, D.U. Himmelstein, D. McCormick and D. H. Bor (2000) *Smoking and mental illness: A population-based prevalence study*, Journal of the American Medical Association, 284, 26062610. doi:10.1001/jama.284.20.2606

[5] R. Sinha, *Chronic Stress, Drug Use, and Vulnerability to Addiction, Annals of the New York Academy of Sciences*, 2008;1141:105-130. doi:10.1196/annals.1441.030.

[6] K. R. Merikangas, E.F. Nakamura, R. C Kessler, *Epidemiology of mental disorders in children and adolescents, Dialogues in Clinical Neuroscience* 2009;11(1):7-20.

[7] R. C. Kessler, P. Berglund, O. Demler, R. Jin, K. R. Merikangas, E. E. Walters, *Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the national comorbidity survey replication* Arch Gen Psychiatry 2005, 62:593602.

[8] Vrijkotte TG, Van Doornen LJ, De Geus EJ. *Effects of work stress on ambulatory blood pressure, heart rate, and heart rate variability. Hypertension.* 2000 Apr 1;35(4):880-6.

[9] Poh MZ, Swenson NC, Picard RW. *A wearable sensor for unobtrusive, long-term assessment of electrodermal activity.* Biomedical Engineering, IEEE Transactions on. 2010 May;57(5):1243-52.

[10] Cohen S, Kamarck T, Mermelstein R. *A global measure of perceived stress* Journal of health and social behavior. 1983 Dec 1:385-96.

[11] Boonnithi S, Phongsuphap S. *Comparison of heart rate variability measures for mental stress detection.* InComputing in Cardiology, 2011 2011 Sep 18 (pp. 85-88). IEEE.

[12] Lu G, Yang F. *Limitations of oximetry to measure heart rate variability measures.* Cardiovascular Engineering. 2009 Sep 1;9(3):119-25.

[13] Wu M, Cao H, Nguyen HL, Surmacz K, Hargrove C. *Modeling perceived stress via HRV and accelerometer sensor streams.* In Engineering in Medicine and Biology Society (EMBC), 2015 37th Annual International Conference of the IEEE 2015 Aug 25 (pp. 1625-1628). IEEE.

[14] Li AW, Goldsmith CA. *The effects of yoga on anxiety and stress.* Altern Med Rev. 2012 Mar 1;17(1):21-35.

[15] Labb E, Schmidt N, Babin J, Pharr M. *Coping with stress: the effectiveness of different types of music.* Applied psychophysiology and biofeedback. 2007 Dec 1;32(3-4):163-8.

[16] Brouwer AM, Hogervorst MA. *A new paradigm to induce mental stress: the Sing-a-Song Stress Test (SSST).* 2014 Jan 1.

[17] Kirschbaum C, Pirke KM, Hellhammer DH. *The Trier Social Stress Test a tool for investigating psychobiological stress responses in a laboratory setting.* Neuropsychobiology. 1993;28(1-2):76-81.

[18] Karstoft KI, Statnikov A, Andersen SB, Madsen T, Galatzer-Levy IR. *Early identification of posttraumatic stress following military deployment: Application of machine learning methods to a prospective study of Danish soldiers.* Journal of affective disorders. 2015 Sep 15;184:170-5.

[19] Galatzer-Levy IR, Karstoft KI, Statnikov A, Shalev AY. *Quantitative forecasting of PTSD from early trauma responses: A machine learning application.* Journal of Psychiatric Research. 2014 Dec 31;59:68-76.

[20] Boser, B.E., Guyon, I.M., Vapnik, V.N.: *A training algorithm for optimal margin classifiers,* In: 5th Annual ACM workshop on Computational Learning Theory, pp. 144152. ACM Press, New York (1992)

[21] Hernandez J, Morris RR, Picard RW. *Call center stress recognition with person-specific models.* In Affective computing and intelligent interaction 2011 Oct 9 (pp. 125-134). Springer Berlin Heidelberg.

[22] Sano A, Picard RW. *Stress recognition using wearable sensors and mobile phones.* In Affective Computing and Intelligent Interaction (ACII), 2013 Humaine Association Conference on 2013 Sep 2 (pp. 671-676). IEEE.

[23] Sharma N, Dhall A, Gedeon T, Goecke R. *Thermal spatio-temporal data for stress recognition.* EURASIP Journal on Image and Video Processing. 2014 Dec 1;2014(1):1-2.

[24] Zhai J, Barreto A. *Stress Recognition Using Non-invasive Technology.* In FLAIRS Conference 2006 May 11 (pp. 395-401).

[25] Julian Bauer. Calm - Real-time Stress Detection on the Apple Watch. http://getcalmapp.com/ (accessed 8 February 2016).

[26] Headspace - Treat Your Head Right. https://www.headspace.com/headspace-meditation-app (accessed 8 February 2016).

[27] Anna Zhulay. Voodoo Stress Relief. https://itunes.apple.com/us/app/voodoo-stress-relief/id982487186?mt=8 (accessed 8 February 2016).

[28] Apple Watch. https://support.apple.com/en-gb/HT204666 (accessed 8 February 2016).

[29] App Programming Guide for watchOS. https://developer.apple.com/library/ios/documentation/General/Conceptual/WatchKitProgrammingGuide/DesigningaWatchKitApp.html (accessed 8 February 2016).

[30] All About Heart Rate (Pulse). http://www.heart.org/HEARTORG/Conditions/More/MyHeartandStrokeNews/All-About-Heart-Rate-Pulse_UCM_438850_Article.jsp (accessed 8 February 2016).