Addressing Mental Health Using Behavioral Biometrics and Machine Learning - A Survey

Saloni Saluja (T00608615)
Thomspon Rivers University
COMP 4980: Behavioral Biometrics

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Abstract

The importance of mental health cannot be overlooked. Today, mental health concerns are becoming a serious problem for individuals across the globe. Statistics indicate that they have been affecting the Canadian youth in huge numbers. Most of the millennials and Generation Zs can be seen walking around with smartphones, smart watches, and other electronic gadgets in their hand. This research paper attempts to identify how we can use this state-of-the-art technology to gather behavioral biometric data from these individuals. One thing to note here is that the data gathered using embedded sensors in these devices is huge. Analyzing this data manually is a bigger and more complicated problem. This is where Machine Learning comes into play. This research paper also attempts to determine if we can use machine learning classifiers to analyze the humongous data acquired using these sensors. For this, we survey novel works conducted by several researchers in this field. We will also attempt to critically analyze these papers to find out the areas that can be researched further. Based on our literature review, we propose a taxonomy for identifying patterns within these works and classify them. Finally, we draw out conclusions to answer on our initial research questions and propose future works that can be done to improve this paper.

1 Introduction

Mental health plays a vital role in people's lives. It is not something that can be swept under the rug. Illnesses caused due to mental health affect people of all ages, education, income levels, and cultures.

1.1 What is the problem?

According to Canadian Mental Health Association, suicide is one of the leading causes of death in both men and women from adolescence to middle age. It accounts for 24% death among people between the age category of 15 to 24 and 16% deaths for people who are anywhere between 25 to 44 year old. [2] In 1999, 3.8% of all admissions in general hospitals (1.5 million hospital days) were due to anxiety disorders, bipolar disorders, schizophrenia, major depression, personality disorders, eating disorders, and suicidal behaviors. [1] The economic cost of mental illnesses in Canada for health care system was estimated to be at least 7.9 Billion CAD in the year 1998, out of which $4.7 Billion was spent in care, and $3.2 Billion in disability and early death. [2]

1.2 Why bother?

Today's youth is tomorrow's future. Mental health has affected a large population of the Canadian youth today. Out of all the illnesses and disorders that exist in the world, "mental illnesses" is the most disabling group of disorders all over the world. It is an unfortunate fact that as per reports, about 10 to 20% of the Canadian youth is affected by a mental illness or disorder. [2] Mental health has always had a stigma attached to it. This stigma presents a serious barrier, not just towards the diagnosis and treatment in the case of an illness, but also towards the acceptance of a person who suffers from it in the society and community where they belong. This stigma is the root cause as to why almost half (49%) [2] of those who feel they have suffered from depression or anxiety have never gone to see a doctor about this problem. They keep suffering and suffering and do not realize that this illness can be treated effectively. Thus, we have come to a point where we are looking at how crucial it is to have a healthy mind in a healthy body and how important it is for people to get help when they need it.

Since mental illness and disorders are still considered to be a stigma in the society, most people who suffer from it do not visit a doctor or get themselves diagnosed. It has been proven with the help of various studies that mental states can be manifested with the help of physiological and behavioral changes. For example, there was a study conducted to find out the association between electrodermal activity (EDA), depression, and suicidal behavior. [10] Electrodermal activity is used to measure variations in the electrical characteristics of the skin which tells us about the state of the body. [20] This study states that hypoactive epidermal response is an established feature of patients affected by depression. The authors also found evidence that monitoring electrodermal activity may be useful to differentiate phases of mood disorders. [10] Thus, medical experts from all around the world are trying their best to integrate physical and behavioral health. Pete Slocombe, who has been working with Medibio's technology for the last 4 years is confident in the ability of biometrics to solve this issue.

Smartphones and other similar devices have demonstrated the potential to provide mental health interventions. [9] Wearable devices such as smartphone and smartwatches have various types of embedded sensors. Examples include physiological sensors (heart rate, dermal activity, etc.) and ambient sensors (ambient pressure, temperature, etc.). By combining the data from these sensors, it is possible to get information on physical activity, location, mood, and social relationships. Knowing this information about a user can be helpful in providing on-time personalized services. However, one of the challenges encountered with this is the huge amount of data that is gathered. Analyzing a large data set manually is quite difficult. This is where Machine Learning comes into action. Machine Learning can be used to extract information from data gathered by the sensors and using this information for constantly monitoring the user's current state. [18]

1.3 How does this research paper address this problem?

In this research paper, we study if different physical and behavioral biometric attributes such as heart rate can be analyzed to decipher a person's mental health. To answer our question, we will conduct a literature review of novel research works about systems that monitor mental health (Mental Health Monitoring Systems – MHMS) using sensors and use machine learning to analyze the data acquired by these sensors. The primary goal of this research paper is to conduct a review and survey various works that illustrate how we can use the technology available today (multi-modal sensors and machine learning) for automatic and adaptive mental health monitoring.

The main contributions of this research paper include: (i) a brief overview of the most recent research in the context of MHMS, (ii) the classification of research works conducted in the field of MHMS, (iii) conclude if behavioral biometrics and machine learning can be used to address mental health (iv) propose of experiments that can be done in the future to improve this work.

The paper is structured as follows:

- Section 2 contains the survey and literature review on various research works done to indicate the possible ways in which the state-of-art technology including sensors and machine learning can be used for MHMS.
- Section 3 proposes a taxonomy or classification for these research works.
- Section 4 concludes the research paper.
- The references are listed at the end of this paper.

2 Literature Review

In this section, we attempt to survey novel research works done in the field of Mental Health Monitoring Systems (MHMS), summarise their findings, and provide a critical analysis on them. Our prime focus is going to be on works that attempt to monitor mental health using multimodal sensors.

1. **Smartphone Ownership and Interest in Mobile Applications to Monitor Symptoms of Mental Health Conditions** [29]

   Summary: This research paper gives us a quantitative analysis from patients' data based on their prevalence of smartphone ownership, the patterns identified from their use, and their potential interest in using mobile

applications on a day-to-day basis to monitor mental health conditions. The results of this study suggested that more than 50% of the people showed interest in applications that they could use for this purpose.

Critical Analysis: The research conducted for their study was only based on a single psychiatry clinic. Thus, the sample size is quite small. This clinic was in an urban area of Boston. So, it doesn't take the opinion of patients who live in the countryside into consideration. The technologies available in the urban area can be drastically different from the ones available in the countryside. Additionally, this study does not take the privacy issues of patients into consideration. Individuals have privacy concerns and this study does not address what kind of data would the patients be unwilling to share.

2. **Smartphones for Smarter Delivery of Mental Health Programs: A Systematic Review** [8]

   Summary: This research paper was designed to review the facts and other evidence that support the "efficacy" of mental health applications for smartphones and other mobile devices. It is aimed at people belonging to all age groups. These applications are designed for conditions such as stress, depression, anxiety, sleep disturbances, suicidal behavior, self-harm, psychotic disorders, and eating disorders. The conclusion of this research paper identified that mental health apps can potentially be used to improve treatment accessibility. However, most of these apps that are available today lack efficacy. Therefore, there is a need to educate individuals regarding the apps that have some evidence regarding their productivity or efficacy.

   Critical Analysis: The sample size considered by the researcher is small. This puts up a restriction on the precision and accuracy of the results. There is also a risk of language bias as only studies from peer reviewed journals were included. The long-term efficacy of these apps was not examined either. Therefore, the long-term effects remain unknown.

3. **A Survey on Human Activity Recognition and Classification** [13]

   Summary: This paper talks about the state-of-the-art technology in Human Activity Recognition (HAR) using wearable devices that have sensors embedded in them. It proposes a taxonomy based on the machine learning approach used by the model. This approach can be supervised or unsupervised learning. The other basis of the established taxonomy was the response time, which varies for online and offline. The findings of this research paper suggested that the growing nature of wearable technology has become a better alternative in providing support services to individuals.

   Critical Analysis: This research paper has the potential scope to increase accuracy. Along with this, further research needs to be done to increase the number of different activities detected by the system.

4. **Mobile Phones as Medical Devices in Mental Disorder Treatment: An Overview** [11]

   Summary: This research paper is based on the idea of using smartphones for the treatment and support of mental disorders. The researchers use HCI techniques to design interfaces whose primary aim is to support therapy. This is done by collecting data from patients' day-to-day activities and using this data to monitor the current state and development of their disorders.

   Critical Analysis: This research paper was missing a taxonomy or classification scheme that would potentially help the reader understand the context in a better way.

5. **Mobile Apps for Bipolar Disorder: A Systematic Review of Features and Content Quality** [23]

   Summary: This research paper was aimed at identifying the apps available for people with Bipolar Disorder (BD) on Google Play Store and Apple's App Store. It evaluates the comprehensiveness and quality of information available via these apps against the assessment tools and guidelines used for the treatment of BD. The conclusion of this study was that most apps fail to provide crucial information that can help users in assessing the usefulness of this app. A major downside to these applications is their lack of privacy policies for the patients.

   Critical Analysis: The apps assessed by the researchers only belonged to the Australian Play Store / App Store. The availability of apps worldwide is certainly going to be different. Therefore, the app has a limited scope.

6. **Mental Health Monitoring System using Artificial Intelligence: A Review** [24]

   Summary: The researchers of this paper attempt to analyze several mental health monitoring systems such as virtual counselling, precision therapy, and diagnostic systems. This analysis is done by reviewing the Artificial Intelligence and Machine Learning algorithms and parameters used in each system. The conclusion of this research proposes a system which uses a combination of the systems listed above and is planned to provide personalized mental care.

   Critical Analysis: The researchers propose a system based on data and conclusions drawn from precision therapy. This serves as an input to a chatbot in addition to some generic questions to the user to increase effectiveness. The diagnostic system can be used for therapeutic treatment and intervention by mental health professionals.

7. **Detecting Depression and Mental Illness on Social Media: An Integrative Review** [6]

   Summary: This research paper aims at to review studies that attempt to observe symptoms associated with mental illnesses on social media using techniques such as screening surveys, users' volunteer membership in an online forum, and other similar techniques. It also attempts to tell the readers about automated detection methods that can be used to identify individuals who are at a higher risk through "large-scale passive monitoring" techniques.

   Critical Analysis: Users that are victim to mental illnesses may get tired and stop generating new posts after a while. They may even deactivate their accounts. In that case, data gathering will be interrupted.

8. **Smartphone Interventions for Long-term Health Management of Chronic Diseases: An Integrative Review** [31]

   Summary: This research paper is aimed at presenting how the long-term use of smartphones can benefit patients battling chronic diseases. The researches found out that mobile applications developed a sense of security among patients. They felt secure knowing that their mental state was being monitored. This encouraged them to manage their health more effectively. They felt like they were being taken care of even outside the hospital.

   Critical Analysis: One major downside here is the limited number of specialized smartphone applications built for long-term management of these diseases. The scope of applications that can be used for this purpose is not wide enough. Developers need to create more such applications that can be utilized by patients for monitoring their disease.

9. **A Systematic Review of Cognitive Behavioral Therapy and Behavioral Activation Apps for Depression** [17]

   Summary: This research was conducted to find out the self-help apps available for people with mental health conditions such as depression. Out of the entire pool of these self-help apps, the researchers attempt to filter out the apps that offer Cognitive Behavioral Therapy (CBT) or behavioral activation (BA). Research indicates that depression can be successfully treated with CBT and BA based self-help interventions. This is especially useful for youngsters and teenagers who use their smartphones very often.

   Critical Analysis: This research work is only taking the apps into consideration that are downloadable in Canada and in English language only. Also, the review only considers the top platforms based on popularity only. Additionally, CBT and BA apps were evaluated against metrics specified by a single expert only.

10. **EEG Seizure Detection and Prediction Algorithms: A Survey** [4]

    Summary: This research paper is based on the use of Electroencephalogram (EEG) signals to analyze brain activity during seizure. This is aimed at patients who suffer from Epilepsy. EEG Signals can also be used for predicting epileptic activities before they occur. This prediction is very useful as it can prepare the individuals before-hand so that they can take appropriate measures. Hence, the researchers attempt to determine the state-of-the-art technology that can be useful for this seizure prediction and seizure detection.

Critical Analysis: The researchers conclude this study by saying that seizure detection and prediction models that use machine learning classifiers are better that the ones that are not implemented using classifiers. However, the paper does not mention the category of classifiers best suited to analyze data sets pertaining to problems like the above.

11. **Wearable Medical Sensor-Based System Design: A Survey** [21]

    Summary: This research paper mentions that Wearable Medical Sensors (WMS) were initially developed to be a cost-effective alternative to continuous health monitoring. However, these systems are being used for much more than that now. The researchers' prime focus is on the goals and challenges faced by WMS-based systems.

    Critical Analysis: It does not conduct any study on the potential challenges faced due to design, development, and implementation of WMS systems.

12. **Mental Fatigue Monitoring Using a Wearable Transparent Eye Detection System** [26]

    Summary: The researchers of this study proposed to measure mental fatigue using a wearable eye detection system which can acquire pupil movement and eye blinking based on the right reflected from the eye. The result of this study was that majority of the participants showed a correlation between workload and the information gathered from the eye detection system.

    Critical Analysis: This research work had an extremely small sample size consisting of 3 men and 2 women only. Along with this, it only focused on participants between the age group of 21-25.

13. **Public Speaking in Virtual Reality: Facing an Audience of Avatars** [28]

    Summary: The aim of this research paper was to decipher a potential cure for social phobia such as public speaking and find out the effectiveness of virtual environments (VEs) for this purpose. The research revolves around the question of real people's emotional response when subject to a virtual audience. After conducting several experiments around this idea, the researchers determined that a speaker's morale is boosted when they perceive that the audience is interested. This reduces their public speaking anxiety.

    Critical Analysis: This work needs further exploration on the factors that are used by speakers (subjects) to determine whether the audience is interested or not. The actual audience reaction has a part to play here, which is something that needs to be considered.

14. **Eye Tracking as Diagnosis and Assessment Tool for Social Phobia** [12]

    Summary: This study performs diagnosis using an eye-tracking system for social anxiety. People with social anxiety exhibit different eye behaviors. For instance, they avoid eye contact. The subjects were divided into focus group and control group. On an average, the experiments show that subjects who have social anxiety exhibit avoidance behavior. This contrasts with subjects who don't show any avoidance behavior.

    Critical Analysis: The sample size here is considerably less. The study only consists of 5 patients who are social phobic and 5 people who are not social phobic. Additionally, the therapy undergone by patients is very short-term (2.5 months only).

15. **Anxiety Detection Using Wearable Monitoring** [7]

    Summary: The prime focus of this study was Social Anxiety Disorder (SAD). In this study, the researchers conduct an experiment to study anxiety levels among participants. The participants were divided into two groups – "No SAD and Mild SAD". The variables under study were – Heart Rate and Spontaneous Blink Rate. The task involved here was giving a presentation in front of professors. During analysis, the researchers found increased heart rates in the Mild SAD group after induced anxiety spans. However, Spontaneous Blink Rate was found to have no effect on Social Anxiety Disorder. The researchers conducted their experiments using wearable devices. Thus, we can infer that they can be used for anxiety detection.

Critical Analysis: The number of participants involved in the experiment was only 8. The number of professors included were 2. Each participant was required to give a speech which was only 10-minutes long. The duration of this study was 45 minutes only. The experiment only considers participants was low or no Social Anxiety Disorder, without considering individuals who have High Social Anxiety Disorder.

16. **Stress Detection for PTSD via the StartleMart Game** [16]

Summary: This research paper studies the positive effect of computer gaming on Post Traumatic Stress Disorder (PTSD). For experiment, the researchers designed a game which forces a player to undergo stressful conditions. A stress detection mechanism was used to measure the skin conductance responses. There was a significant correlation found between physiological responses and the subjects' evaluation of the stressfulness of their experiences. This was represented as pairwise preferences. The research concludes that simulation can be used as a relevant treatment tool for stress inoculation training.

Critical Analysis: This work doesn't include the different types of PTSDs and the degree of severity of each of them, and how computer games can be used for their diagnostic and treatment. The scope of this work also doesn't include how "adaptive game-based solutions" can be used for diagnosis and treatment in psychiatric work.

17. **Towards Independent Stress Detection: A Dependent Model Using Facial Action Units** [30]

Summary: This research paper attempts to find cost-effective ways to track stress levels. The researchers have used video data collected from webcams. Further, they have used Machine Learning Classifiers and performed binary classification on facial action units (AUs). The accuracy for subject independent classification was 74% and that for subject dependent classification was 91%.

Critical Analysis: The number of subjects on which the research was conducted was 5 only. The research needs more data. The researchers only analyze facial action units. They haven't taken any other features into consideration. Their future works will include the performance of emotions such as anger and fear on the data to detect stress.

18. **Wearable System for Stress Monitoring of Firefighters in Special Missions** [27]

Summary: This research paper proposes the use of a telemonitoring wearable system to measure the physiological signals and ambient conditions (temperature and humidity). Their stress level affects their performance at work. Further, they used Machine Learning algorithms to measure stress level in firefighters while on a dangerous mission. The results suggested that this wearable biofeedback system allowed the firefighters to monitor thermal stress and hazards along with the capacity to maintain mental lucidity and accuracy of decisions of the wearer.

Critical Analysis: The implementation harnesses the benefits of e-textile. Although, currently it does not use a hardware platform that supports low power consumption, is less complex, or has high compatibility and is extensible. Also, to validate the system, it needs to be testes by real firefighters in training or perform some simulation exercises.

19. **Multi-Modal Acute Stress Recognition Using Off-the-Shelf Wearable Devices** [19]

Summary: This research paper proposes a multi-model machine learning technique to detect acute stress episodes by using information from various bio-signals and wearable sensors. Additionally, the researchers analyze the contribution of each wearable sensor in stress detection by acquiring physiological signals. Their experiments suggest the possibility of detecting acute stress episodes with an accuracy of 84.3% for test data using multi-modal machine learning techniques with sensor-fusion techniques.

Critical Analysis: The researchers used training set to train their model. Accordingly, they used the test set to test the model on unseen data and the model yielded an accuracy of 84.3%. However, they did not deploy their model on absolute new data to evaluate the predictions of the model.

20. **Inclusion of Respiratory Frequency Information in Heart Rate Variability Analysis for Stress Assessment** [15]

    Summary: This research paper attempts to use Respiratory Rate Heart Rate Variability as stress markers. The researchers collected data corresponding to health young people who were subjected to acute emotional stress. This was induced by modifying the Trier Social Stress Test. The results of this study indicate that joint analysis of respiration and heart rate variability obtained a more reliable characterization of autonomic nervous response to stress. Additionally, the researchers observed that respiratory rate was higher and less stable during stressful situations as compared to relaxed situations.

    Critical Analysis: The limitation of this study was that the method used is valid only for sufficiently peaked spectra, which refers to the intervals when the respiratory rate can be properly estimated. It is not suitable for estimating respiratory rate in stages when the person under observation is talking.

21. **Effects of Controlled Breathing, Mental Activity and Mental Stress With or Without Verbalization on Heart Rate Variability** [5]

    Summary: The objective of this research paper is to determine whether talking or reading (silently or aloud) could affect Heart Rate Variability (HRV). It determines the extent to which these changes require correct interpretation of simultaneous recording of respiratory activity. The researchers studied the effect of free talking and reading, silently and aloud, on respiration rate and blood pressure by comparing spontaneous breathing to controlled breathing. The conclusion of this study was that mental and verbal activities have a huge effect on heart rate variability through changes in respiratory frequency.

    Critical Analysis: The researchers need to quantify respiration. They need to obtain spontaneous conditions though the tested conditions. They also need to emphasize on the effects of speech. The subjects under study were normal, healthy individuals. Therefore, the results of this study are ideally not meant for older patients who are subject to cardiac conditions.

22. **Stress Pattern Recognition Through Wearable Biosensors in the Workplace: Experimental Longitudinal Study on the Role of Motion** [22]

    Summary: This study attempts to perform remote stress identification by testing whether a non-physiological signal of physical activity has the potential to improve the classification of physiological data related to stress which is collected from biosensors. The results of this study indicate that combining physiological signals with non-physiological signals improves stress pattern recognition by emotional detection. These findings are especially useful in the case of wearable devices for stress management when stress is monitored with the user's activity and is not directly observed during measurements.

    Critical Analysis: This research paper does not use cross-validation techniques to build stress-identification algorithms. A more thorough understanding of metrics used for measuring stress can be used to manage the process of stress data collection more efficiently with wearable devices in workplace.

23. **Validity of Mind Monitoring System as a Mental Health Indicator** [14]

    Summary: The researchers of this study have made use of non-invasive methods such as voice to measure an individual's mental health condition. They created a smartphone app for this and to evaluate the validity of BDI (Beck Depression Inventory) and compare this with vitality score. The results of this study indicate a negative correlation between BDI and vitality score. This was a useful method to identify a test subject with a high BDI.

    Critical Analysis: The different recording methods used for conducting the experiments in the above research showed a difference in numerical values. The researchers need to work on eliminating this difference.

24. **A Study on the Development of a Day-to-Day Mental Stress Monitoring System using Personal Physiological Data** [25]

    Summary: This study aims to predict an individual's mental stress level using short-term heart rate variability (HRV). The researchers have gathered data using Photoplethysmography (PPG) signal on a daily

basis for a week. Alongside, they maintained a daily log of stress level. This was done thrice a day for a week for each participant. The subjects performed measurements by themselves in their own living circumstances. The results of this study across subject validation of the proposed system demonstrated a good amount of correlation between true and predicted stress scores. This implied a possibility to generalize the system for a wider population.

Critical Analysis: The limited number of subjects is one downside to this study. A more rigorous study should follow for further examination of the results.

25. **Sensing Technologies for Monitoring Serious Mental Illnesses** [3]

Summary: This research paper focuses on sensing technologies and how they can be used for diagnosing and monitoring patient states for several different types of mental illnesses. Sensing technologies can be used to address the issue of mental health by tracking relevant behavioral, physiological, and social signals.

Critical Analysis: Sensing technologies are still and emerging trend. There is a lot of development that needs to be done in this field before we can integrate these technologies into our existing healthcare system. The key challenges include lack of clinical evidence, privacy issues, and long-term user engagement.

3 Classification and Analysis

Following the literature review, proposed a taxonomy as shown in Table 1. Some of the works that we studied were survey based while others were model, or experiment based. The survey papers attempted to study the research done by others. For instance, in the survey conducted by T. Donker et. al [8], the researchers attempted to compare various smartphone that were designed for patients to monitor their mental health. Other works of study were experiment based. The researchers proposed a design that could be replicated or constructed a model themselves. Some studies were a combination of survey as well as experimentation. These studies attempted to critically review the works of other researchers and finally propose a design that would combine the benefits and minimize the loss.

The second criteria of our taxonomy is based on the mental health condition being studies by the literature. Majority of the works were concentrated on chronic stress, anxiety, and depression. Others laid their research on Bipolar disorder, Schizophrenia, Human Activity Recognition, Suicidal Ideations etc. Very few research works were based on generic mental disorders. These studies discussed about mental disorders in general, without laying focus on one particular disorder.

The next criteria used to differentiate the studies from one another was the technology used for data gathering. Some experiments used smartphones, others used wearable devices such as wristbands. Jakob Bardram et. Al [11] used social media as a source of data to detect depression among individuals.

We also attempted to determine if the researchers used machine learning techniques for data analysis in their experiments. For survey papers, we analyzed whether the researchers studied any machine learning classifiers and applied it to their research. The final basis of our taxonomy is the use of behavioral biometrics in study. The works mentioned below made efficient use of techniques such as facial expressions, blinking pattern, heart rate, brain activity, voice, skin conductance, etc. Some other works studies how smartphone apps are using Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA).

Table 1: Taxonomy

S.No.	Title	Study Type	Condition Under Study	Technology Used	Use of ML Techniques	Behavioral Biometrics Used
1.	Smartphone Ownership and Interest in Mobile Applications to Monitor Symptoms of Mental Health Conditions [29]	Experimentation	Anxiety and Depression	Smartphones	No	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)
2.	Smartphones for Smarter Delivery of Mental Health Programs: A Systematic Review [8]	Survey	Stress, depression, anxiety, sleep disturbances, suicidal behavior, self-harm, psychotic disorders, and eating disorders	Smartphones and Tablets	No	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)
3.	A Survey on Human Activity Recognition using Wearable Sensors [13]	Survey	Human Activity Recognition	Wearable Device, Smartphone Sensors	Yes	Body movement / activity
4.	Mobile Phones as Medical Devices in Mental Disorder Treatment: An Overview [11]	Survey + Experimentation	Depression, Anxiety, Bipolar Disorder, Schizophrenia	Smartphones	Yes	Walking, running, sleeping, shopping, attending work
5.	Mobile Apps for Bipolar Disorder: A Systematic Review of Features and Content Quality [23]	Survey	Bipolar Disorder	Smartphones and Tablets	No	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)
6.	Mental Health Monitoring System using Artificial Intelligence: A Review [24]	Survey	Depression, Anxiety	Smartphones and Wearables	Yes	Physical Activity (Gait - walking, stationary, running), audio (silence, voice, noise)
7.	Detecting Depression and Mental Illness on Social Media: An Integrative Review [6]	Survey	Depression	Social Media	Yes	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)

8.	Smartphone Interventions for Long-term Health Management of Chronic Diseases: An Integrative Review [31]	Survey	Chronic Diseases – Mental Health Problems, Diabetes, Cancer, Overweight, Pulmonary diseases	Smartphone	No	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)
9.	A Systematic Review of Cognitive Behavioral Therapy and Behavioral Activation Apps for Depression [17]	Survey	Depression	Smartphone	Yes	Cognitive Behavioral Therapy (CBT) and Behavioral Activation (BA)
10.	EEG Seizure Detection and Prediction Algorithms: A Survey [4]	Survey + Experimentation	Seizure and Epilepsy	EEG Signals	Yes	Brain activity
11.	Wearable Medical Sensor-Based System Design: A Survey [21]	Survey + Experimentation	Heart Rate, Blood Pressure, Oxygen Saturation, Body Temperature, Blood Glucose, Accelerometer, ECG, EEG	Wearable Medical System (WMS)	Yes	Body movement, blood pressure, brain activity, heart activity, skin conductance, repiration, etc.
12.	Mental Fatigue Monitoring Using a Wearable Transparent Eye Detection System [26]	Experimentation	Mental Fatigue	Wearable Eye Detection System	Yes	Eye movement, Blinking pattern
13.	Public Speaking in Virtual Reality: Facing an Audience of Avatars [28]	Experimentation	Social Phobia and anxiety disorder	Virtual Environment (VE)	Yes	Facial Expressions
14.	Eye Tracking as Diagnosis and Assessment Tool for Social Phobia [12]	Survey + Experimentation	Social Phobia and anxiety disorder	Eye tracking system	No	Eye movement, facial features
15.	Anxiety Detection Using Wearable Monitoring [7]	Experimentation and analysis	Social Phobia, Anxiety Detection	Wearable computing technologies	No	Heart Rate, Spontaneous Blink rate
16.	Stress Detection for PTSD via the StartleMart Game [16]	Survey + Experimentation	Stress detection, Post Traumatic Stress Disorder	Computer games	Yes	Skin conductance responses
17.	Towards Independent Stress Detection: A Dependent Model Using Facial Action Units [30]	Survey + Experimentation	Chronic Stress	Webcams	Yes	Facial Expressions

18.	Wearable System for Stress Monitoring of Firefighters in Special Missions [27]	Survey + Experimentation	Heat and mental stress detection	Telemonitoring Wearable System	Yes	Physiological signals and ambient conditions (temperature and humidity)
19.	Multi-Modal Acute Stress Recognition Using Offthe-Shelf Wearable Devices [19]	Experimentation	Acute stress and mood disorders	Biosignals and wearable sensors	Yes	Physiological signals (ECG, EDA, RSP, BVP, SKT)
20.	Inclusion of Respiratory Frequency Information in Heart Rate Variability Analysis for Stress Assessment [15]	Experimentation and analysis	Acute emotional stress	Chest band based respiratory signal with three orthogonal ECG leads	No	Respiratory Rate and Heart Rate Variability
21.	Effects of Controlled Breathing, Mental Activity and Mental Stress With or Without Verbalization on Heart Rate Variability [5]	Experimentation	Mental stress, mental activity, controlled breathing	Inductive pneumograph, Finapres, Ohmeda, Engle-wood, Colorado	No	Respiratory Rate, Heart Rate variability, Blood Pressure
22.	Stress Pattern Recognition Through Wearable Biosensors in the Workplace: Experimental Longitudinal Study on the Role of Motion Intensity [22]	Experimentation	Mental stress	Wearable Biosensors	Yes	Galvanic Skin Response and Heart Rate
23.	Validity of Mind Monitoring System as a Mental Health Indicator [14]	Experimentation and analysis	Generic mental health conditions	Smartphone	Yes	Voice
24.	A Study on the Development of a Day-to-Day Mental Stress Monitoring System using Personal Physiological Data [25]	Experimentation	Mental stress	Wristbands	No	Pulse rate, Heart Rate Variability
25.	Sensing Technologies for Monitoring Serious Mental Illnesses [25]	Survey	Depression, Anxiety disorder, bipolar disorder, schizophrenia, suicidal ideations and others	Social Signals	No	Facial Expression, Heart Rate Variability, Eye Movement, Electrodermal Activity

4 Conclusion

The main aim of this research was to find out if behavioral biometrics and machine learning techniques can be used to address mental health concerns. After conducting a literature review of novel research works, we found out that behavioral biometrics such as facial expressions, voice, pulse rate, eye movement, body temperature, etc. have the potential to be used as a means to find out the mental state of an individual. The data gathered by these devices is huge. It is difficult to analyse such a huge amount of data manually. This is where machine learning comes into play. Several machine learning classifiers such as Support Vector Machines (SVMs) can be used for data analysis. Other than technological devices such as smartphones, wearables, smart glasses, etc. we can also social media such as Facebook, Twitter, etc. to gather data about how an individual is feeling.

Future works for this study include designing a machine learning model. This model would analyze data collected from biosensors. Specifically, we would focus on behavioral biometric data such as facial expressions, eye movements etc.

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