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Sensor-based Measurement of Physiological Response to Test Anxiety

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Sensor-based Measurement of Physiological Response to Test Anxiety

Abstract

Test anxiety is a prevalent psychological issue among higher-education students, particularly those seeking degrees in STEM (Science, Technology, Engineering, and Mathematics) [1]. Test anxiety is an adverse emotional reaction when faced with a testing circumstance or comparable evaluative atmosphere. Numerous studies on the impact of test anxiety on STEM students' academic performance have been undertaken. Understanding the complex link between test anxiety and academic achievement is critical for developing evidence-based solutions to help students succeed in STEM fields. Despite substantial research on college students' test anxiety, there are major gaps in the literature, particularly in the context of engineering education.

Biometric data can give valuable insights into the physiological responses to test anxiety, influencing the creation of more effective therapies to help students cope with this issue. By measuring physiological signs, such as heart rate, blood pressure, and skin conductance, researchers may acquire a more objective and nuanced knowledge of the link between test anxiety and academic success. This study's proposed research question is "What types of sensors have been found to be most effective in measuring physiological data related to anxiety for research purposes?". This study aims to identify the best biometric sensors for collecting data on engineering students' physiological markers of test anxiety based on a narrative literature review. Preliminary research shows a dearth of data linking physiological data to test anxiety specifically, so this review expands its search to anxiety in general context. Qualitative thematic analysis was conducted as part of the research to identify the types of sensors used in prior studies on test anxiety and to assess their usefulness for measuring physiological responses to anxiety. It was found that heart rate and heart rate variability (HRV) are two of the most common biometric markers used to indicate test anxiety in previous studies.

Other sensors reported in literature include electrodermal sensors, blood oxygen saturation sensors, and thermal biomarkers; however, there are less studies published using these sensors. There is much room for improvement when using sensors to measure physiological response, as accuracy levels are still not high enough for these sensory readings to be individually used for a comprehensive assessment. Typically, multiple physiological responses must be used in conjunction to achieve acceptable confidence in readings, and research is still underway to identify sensors to measure physiological responses that can uniquely identify fluctuations in anxiety. Ultimately, understanding the impact of test anxiety and its induced physiological effects on students can provide educators with more knowledge and insights on how to further improve delivery of and assessment in engineering education.

Introduction

Test anxiety is a prevalent psychological issue among higher-education students, particularly those seeking degrees in STEM (Science, Technology, Engineering, and Mathematics) [1]. Test anxiety is an adverse emotional reaction when faced with a testing circumstance or comparable evaluative atmosphere. It is classified as performance anxiety, in which students display physiological, cognitive, and behavioral symptoms that might hinder academic performance [2].

Numerous studies on the impact of test anxiety on STEM students' academic performance have been undertaken. Test anxiety is particularly important for STEM student context, especially given the fact that STEM majors are very heavily exam based and require plenty of standardized tests; also, the bulk to test anxiety research has been conducted by psychology researchers with mainly psychology students as the participants. In a systematic literature review, Hembree discovered a substantial negative link between test anxiety and academic success in various subject areas, including mathematics and science [2]. Similarly, Zeidner discovered that test anxiety strongly predicted poor academic performance in STEM courses, even when past academic achievement and other characteristics were controlled for [3].

Several studies have also examined the test anxiety disparities between male and female STEM students. A study by Putwain revealed that female students reported higher levels of test anxiety than male students, with the gender gap being particularly prominent in STEM disciplines [4]. Other research has shown that female students' greater levels of test anxiety may be due to gender stereotypes and societal expectations about women's math and science aptitude.

Understanding the complex link between test anxiety and academic achievement is critical for developing evidence-based solutions to help students succeed in STEM fields. Despite rising awareness of the consequences of test anxiety on STEM students, the literature still leaves many unsolved concerns. Further research is needed on the elements that lead to test anxiety in engineering students and treatments to assist students in coping with and overcoming test anxiety.

Despite substantial research on college students' test anxiety, there are major gaps in the literature, particularly in the context of engineering education. Although there is some indication that engineering students may suffer more test anxiety than their colleagues in other STEM fields, there has been relatively little research on this issue. The lack of literature on test anxiety among engineering students is a significant gap in the discipline, as these students encounter hurdles in their academic and professional lives.

Biometric data may give valuable insights into the physiological causes of test anxiety, influencing the creation of more effective assessment methods to minimize this issue. By measuring physiological signs, such as heart rate, blood pressure, and skin conductance, researchers might acquire a more objective and nuanced knowledge of the link between test anxiety and academic success.

This study's proposed research question is "What types of wearable sensors have been found to be most effective in measuring physiological data related to anxiety for research purposes?". This study aims to find the best biometric sensors for collecting data on engineering students' physiological markers of test anxiety based on literature review. Qualitative thematic analysis will be conducted as part of the research to identify the types of sensors used in prior studies on anxiety and to assess their usefulness for measuring physiological responses to test anxiety in future work.

Background

Recent estimates show that over one-third of the global population will experience some mental health disorder(s) over their lifetime [5]. While modern medical institutions are well equipped to treat patients with diagnosed mental conditions, people with milder symptoms are seldom able to receive necessary treatment due to their condition not falling under the required diagnostic criteria [6]. Without access to medical diagnosis and treatment, many such individuals continue to suffer from their mild/medium symptoms until their condition deteriorates to the point of needing necessary medical attention, resulting in the need for more effective and accessible diagnostic techniques to prevent mild mental disorders from regressing.

To this end, extensive research has been conducted into using sensors to measure physiological responses to various emotions, particularly in the form of smart wearable devices that allow for continuous monitoring and self-diagnosis. Various physiological responses have been linked to anxiety levels in individuals, and sensors capable of detecting these responses have been increasingly incorporated into these smart wearable devices to enable quick initial diagnosis and drive the development of digital interventions to help treat mild disorders [6].

Heart rate has been commonly considered to be a reliable physiological indicator of stress and anxiety. An elevated heart rate is often characteristic of an individual suffering from increased stress, and heart rate sensors are commonly used to monitor and track heart rate and heart rate variability (HRV) [7]. Heart rate variability measures changes in heart rate over time, an indication of autonomic functioning. This variability in heart rate reflects the body's ability to respond to changes in stimuli; a higher HRV indicates a balanced autonomic nervous system (ANV) that is adaptive to different environments, while a low HRV indicates an imbalanced

ANV. For individuals with anxiety, this means that the natural “fight or flight” response is operating in overdrive, resulting in added stress [7].

Sensors used to measure heart rate typically use either Electrocardiography (ECG) or Photoplethysmography (PPG) technology [7]. ECG relies on the measurement of electrical signals on the skin's surface to measure HRV. The nerve and muscle cells, including those of the heart, communicate via electrical and chemical signals, which can be measured on the skin’s surface. Changes in the electrical voltage are plotted on a graph, creating a visual representation of an individual’s heartbeat, and allowing for monitoring of their heart rate [7]. On the other hand, PPG relies on light's reflection to measure heart rate. Light from an LED source is targeted on the person’s skin, with some of the light reflected into a photodiode. As the heart beats, the continuous cycle of increased and decreased blood pressure results in varying light being reflected into the photodiode, with the resulting pattern and changes in time between pulses used to measure heart rate [7].

Heart rate monitoring is a mature technology, with currently used ECG medical sensors having an extremely high level of accuracy. While not as accurate as ECG medical sensors, wearable smart devices with built-in optical (PPG) heart rate monitors also exhibit acceptable levels of accuracy, particularly during times of low levels of physical activity. A recent study comparing the accuracy of the Polar H7 heart rate monitor (ECG based) and a wearable fitness tracker (PPG based) concluded that the mean absolute percentage error (MAPE) was between 3.77% and 4.73% across age groups, proving the relative accuracy and reliability of smart wearable devices for heart rate and heart rate variability monitoring [8].

Other physiological responses include electrodermal activity, a measure of the skin’s electrical conductivity variation, usually influenced by secretion from the sweat glands. As increased stress is typically attributed to increased sweating, electrodermal activity is often used as a physiological response to monitor stress and anxiety levels using sensors [9]. Additionally, blood oxygen saturation and breathing rates are also usually used to measure stress. When a person suffers from increased anxiety, they typically exhibit faster but inefficient breathing cycles, resulting in less oxygen being drawn in and causing lower oxygen levels in the blood.

A challenge with using wearable sensors to measure physiological stress response is that they are less accurate compared to specialized medical equipment, particularly when stress levels are generally more elevated than usual [8]. Using specialized medical equipment in academic testing situations is not feasible. So, a combination of multiple physiological responses must be gathered using wearables to monitor test anxiety more accurately. Incorporating insights from human factors engineering, this literature review investigates the integration of biometric sensors within STEM education to understand the dynamics between test anxiety and physiological responses among students [10].

Methods

For this literature review, 35 studies were extracted and reviewed from multidisciplinary sources and database searches, after which titles and abstracts were screened based on relevance. Nine papers were shortlisted and used as part of this literature review following the screening exercise. The following table illustrates the inclusion criteria used for the studies:

Table 1: Inclusion Criteria

Inclusion Criteria	Position
Does this study collect biometric data from a wearable device?	Yes / no
Does this study collect physiological data to measure anxiety or stress?	Yes / no
Is the study peer-reviewed?	Yes / no
Is the study written in English?	Yes / no

Qualitative analysis was conducted via in vivo coding, using reported language and themes rather than researcher-derived codes. Each study was examined in depth, and common themes surrounding sensor choice were extracted. The common themes were mapped as per appearance in each study, with the mapped themes used to synthesize findings on various sensor use and effectiveness.

Results and Discussion

Of the nine studies chosen, a variety of common themes surrounding sensor choice and use are evident, with some more prevalent than others, as shown in Table 2 below [5-7, 11-16].

Table 2: Qualitative Systematic Analysis of Common Sensor Themes

	Heart Rate	Heart Rate Variability (HRV)	Electrodermal Activity (EDA)	Blood Pressure	Thermal Biomarkers	Oxygen Saturation	Breathing Rate
Paper 1[11]	X	X	X	X			
Paper 2[12]	X	X					
Paper 3[13]	X				X	X	
Paper 4[7]	X	X		X			
Paper 5[5]	X		X				
Paper 6[14]	X						X
Paper 7[15]			X				
Paper 8[6]	X	X					
Paper 9[16]			X				

Cardiovascular response, both heart rate and heart rate variability, were the most studied factors, with almost all involving heart rate monitoring to measure anxiety. A person's heart rate can often be directly related to their anxiety levels, and its ease of measurement makes heart rate monitors an effective sensor of choice. However, as the heart rate can also fluctuate based on physical activity, heart rate variability and blood pressure measurements are often used in conjunction with heart rate monitoring to increase detection accuracy [11].

Four of the chosen publications studied electrodermal sensors and it is noteworthy to mention that the studies using EDA as a measure are very recent and are gaining traction.. As explained earlier, the electrodermal response is measured by the sweat glands' excretion level. This factor may also be affected by the physical environment of the test subject, such as humidity, temperature, variation in bodily response, in addition to their mental state. Electrodermal measures have been less studied with regards to anxiety correlations when compared to cardiovascular measures, but the results look promising [11].

Blood pressure, thermal markers (body temperature), oxygen saturation, and breathing rates were less commonly used as physiological biomarkers in the studies found these measures may have even lower correlations to stress than electrodermal and cardiovascular responses, as a person's physical health and environment may play a much larger role than stress or anxiety alone. Identifying the stress-based response would be more complex than heart rate monitoring. While low oxygen levels in the blood may be a sign of stress-induced shallow breathing, other medical conditions, such as asthma, also contribute to this effect, increasing the complexity of using this measure as an indicator of stress alone [17].

Conclusion

Currently, the most common method for measuring test anxiety in literature is through perception-based surveys, which can often be very subjective. Through combining existing validated surveys with objective biological data, researchers can get a better understanding of how test anxiety fully impacts students both physically and mentally. Future work involves analyzing the various sensors, such as ECG and PPG, and pairing them with devices on the market that can collect as many meaningful biological markers as possible.

Heart rate monitoring, combined with heart rate variability and blood pressure measurements, can be an effective tool for measuring stress based on cardiovascular response. The ease of use and sophistication of modern heart rate monitors allows for adequate identification and diagnosis of increased anxiety and can serve a crucial role in its treatment. Other sensors used are electrodermal sensors, blood oxygen saturation sensors, and thermal biomarkers; however, they are less commonly used due to a lower correlation of these physiological responses to variations in stress. However, there is still much room for improvement when using sensors to measure physiological response, as accuracy levels are still not high enough for these sensory readings to be individually used for a comprehensive assessment. Typically, multiple physiological responses must be used in conjunction to achieve acceptable confidence in readings, and research is still underway to identify sensors to measure physiological responses that can uniquely identify fluctuations in anxiety.

Future Work

Further exploration is warranted to analyze and optimize the capabilities of different sensors, particularly those capable of capturing meaningful biological markers associated with stress and anxiety. Heart rate monitoring, when combined with heart rate variability and blood pressure measurements, emerges as a particularly promising approach for assessing anxiety levels based on cardiovascular responses. Leveraging the advancements in modern heart rate monitors offers a convenient and sophisticated means of identifying and diagnosing heightened anxiety, thereby facilitating its management and treatment. Through the application of human factors principles, such as optimization of system usability and human-machine interaction, investigating how these sensors capture and interpret physiological cues indicative of emotional states during testing scenarios is imperative for future advances in this field.

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