REVIEW ARTICLE

Stress Monitoring Device and its Future Direction

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ABSTRACT

Stress and mental health have become a global concern as a result of the COVID-19 pandemic. This review highlights the technologies applied to stress monitoring with up-to -date literature on psychological and behavioural evaluation for stress detection. The working principle and potential of these stress identifiers, particularly physiological signals are explored. Researchers have been directing their interest in producing reliable and wearable devices to detect and prevent stress and panic attacks. The breakthrough of biochemical-near-infrared stress monitoring devices will facilitate medical practitioners in the early detection of stress and panic attacks. The review seeks to explore the types of methods used to detect stress as well as the pros and cons of the available technology while providing a new solution for future implications of stress monitoring detection devices.

STRESS

Stress is a natural biological response to stressors that affect people of all ages. Several daily life activities such as studying, working, and performing domestic tasks may be the source of stress. Individuals vary in the way they infer and react to stressors. Furthermore, prolonged stress can result in many serious health problems, either mental or physical health. Apart from mental health disorders such as anxiety, depression and personality disorders, prolonged stress can cause or worsens other health problems like cardiovascular diseases (for example, high blood pressure, abnormal heart rhythms, heart attacks, and stroke, gastrointestinal problems (such as GERD), diabetes, obesity and other eating disorders, menstrual problems and sexual dysfunction.[1,2] This is due to the autonomic nervous system that is responsible for many functions that we control without thinking. Part of the autonomic nervous system is the sympathetic nervous system which response to dangerous or stressful situations. The sympathetic nervous system activates to speed up our heart rate and deliver more blood to areas of our body that need more oxygen or other responses to help us get out of danger. It is a very efficient system but overresponse due to stress will cause negative impact to us.

The body's stress response is regulated by the hypothalamic-pituitary-adrenal (HPA) axis, which controls the release of hormones namely cortisol, ACTH, adrenaline, and noradrenaline.[3] These hormones result in several behavioural changes (e.g., change in facial expression and blinking rate) and physiological responses such as higher respiration rate and blood pressure. Cortisol particularly, plays a role in the maintenance of blood pressure by increasing the number of receptors that are involved in controlling the blood vessels diameter. However, excessive release of cortisol causes an increase in the blood vessels contraction and will lead to an increase in blood pressure.

Stress: Causes and Current Challenges

Numerous situations and factors can contribute to stress in the daily lives. Different age groups may have different factors that trigger stress. According to Murison[4] academics, finances, relationships, careers, and time management are the most common sources of stress for students. Meanwhile, compared to students who have yet to enter the job market, the working class may confront

numerous sources of stress. According to Faisal et al[5] unsupportive relationships with co-workers, inefficient management, severe workload, job instability, impaired communications, and workplace conflicts are factors that contribute to job stressors. These statements are supported by The American Society Association[6] that Matures are less likely than other generations to report feeling depressed or sad as a result of stress as compared to millennials, Gen X and Baby Boomers.

Aside from that, one of the most significant thing contributing to stress for many individuals around the world is the COVID-19 pandemic. Apart from being a medical phenomenon, this pandemic affected many people and led to substantial adverse effect on mental health such as the surge in stress, anxiety, xenophobia, social isolation and stigma.[7,8] According to Fofana et al,[9] those who were under lockdown were more prone to exhibit symptoms of stress, sadness, insomnia, emotional exhaustion, and post-traumatic anxiety due to loss, financial disruption, lack of entertainment, and educational activities.[7] The World Bank's COVID-19 High Frequency (HiFy) Household Monitoring Survey conducted between 18th May to 16th June, 2021 found that one-third of Malaysians experienced work disruptions and 27% who continued working suffered reduced income. Additionally, the prevalence of suicidal attempts were also increased.[11]

Since stress elevates mental health and medical problems,[12] effective tools or devices for stress assessment and management in real-time are increasingly warranted to prevent the negative impact of stress on individuals, society and the global burden of disease. The available devices in the market are mostly not able to detect stress at early stage. In most cases, it is only detected after its effects were seen psychosomatically hence the detrimental effects of stress have begun affecting a person's body. Therefore, with effective tools or devices that is more sensitive, many ailments that stem from stress such as stroke, cholesterol, high BP, and cancer can be prevented through early detection. Moreover, a more reliable stress detecting device may reduce the 'karoshi deaths' i.e 'death from over work'.

Stress Monitoring

Stress can affect an individual's overall body health in addition to their mental health.[12,1,3] The effects of stress can be avoided in the early stages by regularly monitoring stress using a variety of approaches. Continuous stress monitoring is recognized to help individuals who endure repetitive stress and may have uneven physical and mental functioning.[2]

Golgouneh and Tarvirdizadeh[1] stated that psychological evaluation, behavioural responses (e.g., facial expression, voice, etc.) and physiological signals (e.g., electrocardiography, photoplethysmography, galvanic skin response, etc.) are three approaches to detect stress. Therefore, this study aimed to explore the working principle and potential of these stress identifiers, particularly physiological signals, which are frequently used in today's world.

STRESS MONITORING TECHNOLOGY

Psychological and behavioural evaluation.

There are several methods to measure and monitor the stress levels of individuals as mentioned by Golgouneh and Tarvirdizadeh[1], such as psychological analysis, behavioural evaluation, and physiological signals. These three methods involved different techniques as it used different samples from various sources. In the case of psychological evaluation, it examines people's minds and mental states, particularly those that are related to personality, emotion, conduct, and cognition. Kaklauskas et al[13] explained that self-report surveys are still the most common method for learning and diagnosing people's emotions and moods. Apart from that, Crosswell and Lockwood,[14] stated that self-reports surveys can measure stressor exposures and stress responses. Individuals' stressors can be measured through self-report questionnaires such as a checklist of life events that are checked by an interviewer. Apart from self-reports which are considered as the simplest method, behavioural evaluation can also measure stress responses. Kaklaukas et al[13] explained that behaviour describes how a person

reacts in a given scenario based on customary etiquette, standards of conduct, or common place behaviours, and behavioural features, in general it reveals the person's psyche.[13] Furthermore, the behavioural responses mentioned by Alberdi et al[15] can include posture, facial expressions, speech analysis, mobile phone usage, computer exposure, keystroke and moused dynamics, text linguistics, and smart environments. It is known that the way someone delivers their speech changes during stress.[16,17] An assessment for stress was conducted by Aguiar et al[17] using speech as an indicator. Apart from that, Lu et al[16] proposed a system using smartphones that can detect stress using voice analysis. It can identify stress either in indoor or outdoor environments for multiple individuals.

Physiological signals as stress markers

Aside from utilizing psychological and behavioural evaluations to identify stress, there is another way that employs markers derived from bio-signals, known as physiological signals. This method can be grouped into two classes of signals which are cerebral (e.g., electroencephalography, functional magnetic resonance) and peripheral (e.g., biological activity, heart rate, temperature).[19] The physiological signals for instance can be heart rate variability (HRV), electro-cardiography (ECG), electromyography (EMG), electroencephalography (EEG), galvanic skin response (GSR), photoplethysmography (PPG).[1]

Electrocardiography (ECG), Photoplethysmography (PPG), and Heart Rate Variability (HRV)

In stress-related studies, it is known that the most widely used methods are HRV and ECG.[1] HRV is a measure of the variation in time between heartbeats, and it is generally use to monitor the stress levels of individuals by assessing the balanced of sympathetic and parasympathetic nervous systems (of the autonomic nervous system) control of the heart.[20]

HRV analyses can assess changes in neurological systems where sympathetic activity leads to an increase in low-frequency HRV power, which is thought to be related to stress. In addition, the activation of parasympathetic will increase the HRV. Chen et al[21] stated that when the parasympathetic nervous system is repressed as a result of sympathetic nervous system activation, adrenaline and noradrenaline chemicals are secreted, causing the fight-or-flight response. This makes the blood pressure (BP), heart rate (HR), skin conductance, and muscle tension increase and decrease of HRV. If it is vice versa, the opposite of fight-or-flight reaction which is the rest and digest responses would then take place.

ECG is considered the mainstream bio-signal in stress-related studies.[22] The ECG represents the graphic of the electrical signal through the heart muscles (Figure 1) during the cardiac cycle (i.e. the contraction and relaxation of the heart).[23,24] The electrical signals are measured using electrodes placed on the chest and the left and right side of the arms and legs. The waves on an ECG namely P wave, QRS complex and T wave represent atrial depolarization, ventricular depolarization and ventricular repolarization, respectively. The heart rate is calculated from the intervals between the different waves. The HRV can be obtained from assessing the variation of time in milliseconds between two heartbeats (also known as RR interval).[19]

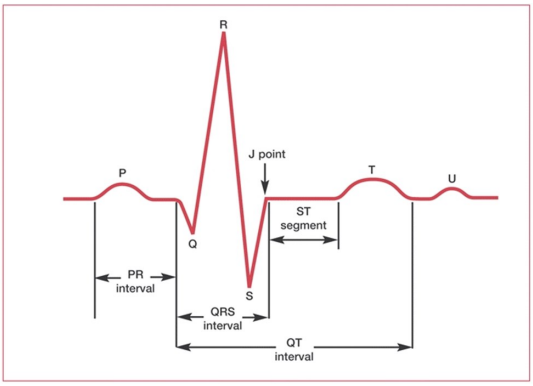

Figure 1: Example of the basic pattern of electrical activity across the heart[27]

Galvanic Skin Response (GSR)

GSR is another prominent bio-signal that is both simple and affordable.[1] It is a device that detects human emotion and monitors the signals emitted by human sweat glands that increases activity with the change in emotion.[28] Sweat is produced due to the reaction of its gland to the sympathetic nervous system activation that is commonly associated with stressful events. A study conducted by

Han et al[24] reported that skin conductance can indicate emotional arousal. According to Golgouneh and Tarvirdizadeh,[1] the activity of the gland is assessed by passing a tiny electrical current through two silver-coated (Ag) electrodes to the skin surface. The tiny electrical current, approximately 0.5 until 3.0 volts, is sent through the body to detect the variation in conductance.[2]

Electromyography (EMG) and Electroencephalography (EEG)

The EMG is a device that measures skeletal muscle electrical activity. It can monitor a person's stress levels by recording their facial expressions as they sleep to detect specific patterns in certain motions (for instance the act of clenching by the masticatory muscles).[30] The EMG signal is used because of its efficiency and the measurement of the muscle electrical activity is displayed as a function of time in terms of frequency, amplitude, and phase.[31] The action potential of the EMG signals, shows higher amplitude when the muscles are exposed to stressors or stressful events compared to resting.[19] Apart from that, the EEG can measure brain activity in relation to stress.[32] It is an instrument to monitor and measure the variations of electrical activities in the brain. It is well known that when engaged in physical activities, the human brain produces electrical signals. The signals can be acquired and used to obtain data for assessing the mental health status like stress and disorders. The EEG signals are grouped into five frequency bands as shown in Table 1.[33]

Table 1: EEG Frequency Data.[33]

Band	Frequency	Activity
Delta	0.5 - 4 Hz	Deep Sleep
Theta	4 - 8 Hz	Drowsiness, Light Sleep
Alpha	8 - 13 Hz	Relaxed
Beta	13 - 30 Hz	Active Thinking, Alert
Gamma	More than 30Hz	Hyperactivity

THE PROS AND CONS OF STRESS MONITORING TECHNOLOGY

The Pros and Cons of Psychological and Behavioural Evaluation

The psychological examination which includes mental condition analysis such as psychometric questionnaires and self-reporting assessments have been used over the years in view of its simplicity and low-cost approach. Despite its benefits, psychometric surveys are not objective and are rarely used.[22] The questionnaires are rather subjective and influenced by some individuals' conditions and opinions and by their definition of stress.[34] Moreover, according to Alberdi,[15] people fill out surveys on stress only when they are experiencing mental disorders as the consequences of the prolonged stress and possibly after they are informed by family or friends which may be too late. Besides, most questionnaires do not include information on the stressors or the evolution of stress levels. Thus, the surveys are not able to detect small changes that suggest early signs of stress or a major mental health problem.

The behavioural evaluation is an easy method which does not require advanced technology like physiological evaluations, but it does have disadvantages. Ayata et al[35] claimed that using solely the speech or facial signals to determine stress is unreliable, especially when participants tend to hide their emotions. Hence, behavioural responses like facial expressions are frequently integrated with physiological signals and technologies like galvanic skin reaction (GSR).

The pros and cons of physiological signals

Markers from bio-signals, also known as physiological signals, have been extensively used to detect stress by means of electrocardiography (ECG), electromyography (EMG), electroencephalography (EEG), galvanic skin response (GSR), and photoplethysmography (PPG). These techniques collect data of the quality and seriousness of a person's internal emotional experience, and hormones which are shown to be a reliable tool in sensing stress, nevertheless it has some weaknesses when compared to psychological and behavioural assessments.[15]

Primarily, in a hospital setting the ECG device typically is used to monitor heart rate (HR) and heart rate variability (HRV). The ECG device can assist healthcare staff in detecting any health disorders, particularly heart-related diseases. Despite its widespread use in healthcare, it does have significant disadvantages. ECG device, according to

Chen et al,[19] is not ideal for daily usage because they are expensive, inconvenient, and only widely available in healthcare facilities such as the hospitals and not readily accessible to the general population and determining patients' stress levels throughout the day.

Alternatively, a cheaper and more convenient alternative is the PPG. The PPG has a less expensive optical approach for detecting and measuring minor variations in light intensity reflection associated with the blood volume.[36] On top of that, Golgouneh and Tarvirdizadeh[1] stated that the PPG is well-known in both clinical and non-clinical settings due to its extensive physiological data delivery and ease of use but can be highly inconvenient in real life (while using the PPG with a smartphone, users need to guarantee that their hands are always in a stable position in front of the camera to avoid measurement errors.[25]

The GSR has been the favourite because of its low-cost and adequate sensitivity,[28] its excellent signal in detecting stress,[1] and commonly used in smart rings or wristbands.[24] Even so, it still has fundamental flaws, such as the GSR inability to distinguish between stressed and non-stressed states when attempting to categorize stress beyond two levels. However, the GSR efficiency increases when it is combined with another physiological signal, such as the PPG.[37]

Aside from that, the EMG data are easy to manage in comparison to the rest of the physiological data.[30] Users can remain in their familiar surroundings while data is collected. Furthermore, by placing the electrodes on the skin's surface, EMG signals can be readily observed. However, it is inconvenient for daily use as it requires the use of application of electrodes in the existing technique.[38] The EMG system requirements, according to Orguc et al,[30] can be challenging because it is important to collect a high signal without interference to comprehend signals behaviour.

Finally, the EEG signals provide a vision of the brain signals that have variability and dynamics[39] while giving exact readings and useful data about the brain's activity. However, it can be inconvenient because the electrodes must be placed closely to the scalp[40] during the measuring process, thus limit the patient activities.

FUTURE DIRECTION

The Biology of Stress and the Role of Cortisol

A biological event occurs at the hypothalamic-pituitary-adrenal axis which is the stress response pathway, whenever our body receives inputs or stimulus on the stressors. The stress hormones cortisol, noradrenaline and adrenaline are released and bind to receptors on the cells. Cortisol receptors particularly are found everywhere in the body including the brain. However, cortisol is also an important hormone for other types of biological processes. Therefore, there are resting cortisol level and reactive cortisol level. The resting cortisol level is observed in the early morning and early night. Whereas the reactive cortisol level is observed when responding to a stressor. For monitoring purposes, the reactive cortisol level is the target of measurement when the body receives stressor and induce signals above the baseline. Monitoring stress through cortisol levels has been applied for several years but it involves an invasive procedure, venepuncture in order to withdraw blood sample and measure the cortisol level. Therefore, finding a new alternative method in detecting cortisol in the blood should be explored.

Near-infrared (NIR)

NIR refers to the scientific method of using near-infrared radiation to analyse samples for compositional or characteristic features. In defining Near-Infrared Reflectance, NIR has also been used. NIRS (Near Infrared Spectroscopy) and NIT are other equivalent concepts (Near Infrared Transmission spectroscopy). All these approaches are connected and depend on the use of near-infrared light to identify components. NIR is an electromagnetic spectrum area that has unique features that make it very useful for characterizing materials. The area of the NIR is from 700 nm to 2500 nm can detect cortisol at the range of 1600-1750nm (https://spectrabase.com/spectrum/AqI5ohyEP0J). NIR interacts

with OH, NH, and CH bonds in this region, and with each bond form, specific wavelengths (frequencies) are related. It has been used in many applications based on the principle that the different bonds that exist in the chemical structure of the identity compound will absorb NIR light at a different strength which then gives the characteristic of individual compounds. Therefore, it is expected that cortisol the stress hormone will also give a distinct characteristic in its absorption ability which then can be translated into another signal such as voltage by the sensor. Further research in this area is important and should be encouraged so that responsible research finding that benefit the community with less negative impact is not neglected.

CONCLUSION

Stress is a natural biological phenomenon of fight-or-flight mechanism which tells us on how to respond to the stressor. However, uncontrolled stress may cause problem to mental health and physical health. Recent COVID-19 crisis made the situation worse. Many methods were developed to detect stress such as biochemical, psycho-social and physiological method. However, each of the methods has its own advantages and disadvantages. Therefore, a non-invasive, real-time measurement, practical and able to give a good indication of stress level which correlating changes on infrared reading due to cortisol absorption is an advantage.

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