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SMART WEARABLE STRESS MONITORING DEVICE FOR AUTISTIC CHILDREN

Awais Gul Airij[a], Rabia Bakhteri[b*], Mohd Khalil-Hani[a]

[a]VeCAD Research Group, Department of Electronics & Computer Engineering, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Sightline Innovation Inc., Winnipeg, Manitoba, Canada

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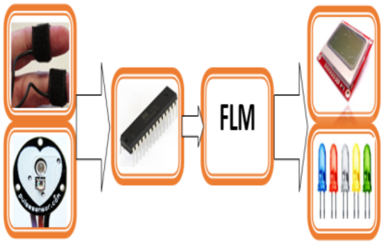
*Corresponding author
rbakhteri@sightlineinnovation.com

Graphical abstract



Abstract

Vital sign monitoring is the process of recording human physiological signals in order to determine the mental stress level. High stress levels can prove to be dangerous especially for certain individuals such as autistic children who are not able to express mounting levels of stress before it leads to a full anxiety attack. This paper presents the prototype design of a real-time embedded device that accurately measures heart rate and galvanic skin response (GSR) in a non-invasive and non-intrusive way which is then used by the intelligent decision making module that uses fuzzy logic to determine the stress level of the user. Such a device could be used with autistic children in order to give early warning of an impending anxiety attack and help adults to prevent it from happening. The prototype was designed using Arduino mega platform and tested with 35 clinical patients in three experimental settings targeted to induce low stress, medium stress and high stress response. Initial results have shown that the device is capable of detecting and displaying the various stress levels efficiently.

Keywords: Stress, tantrums, seizures, autistic children, anxiety

Abstrak

Pengawasan tanda vital adalah proses rakaman isyarat fisiologi manusia untuk menentukan tahap tekanan mental. Tahap tekanan yang tinggi boleh menjadi berbahaya terutama untuk individu tertentu seperti kanak-kanak autistik yang tidak mampu untuk meluahkan tahap meningkat tekanan mental sebelum ia membawa kepada serangan panik. Kertas kerja ini membentangkan reka bentuk prototaip bagi peranti masa nyata terbenam yang mengukur kadar jantung dan tindak balas kulit galvanic (GSR) dengan cara yang bukan invasif dan bukan instrusif yang kemudiannya digunakan untuk membuat keputusan menggunakan modul logik kabur untuk menentukan tahap tekanan pengguna. Peralatan tersebut boleh digunakan kepada kanak-kanak autistik untuk memberi amaran awal serangan panik akan berlaku dan membantu orang dewasa untuk mengelakkan ia daripada berlaku. Prototaip ini telah direka menggunakan peranti Arduino Mega dan diuji dengan 35 pesakit klinikal dalam tiga fasa eksperimen yang disasarkan untuk menghasilkan tindak balas tekanan rendah, tekanan sederhana dan tekanan tinggi. Keputusan awal menunjukkan bahawa peranti mampu mengesan dan memaparkan pelbagai tahap tekanan dengan tahap ketepatan yang tinggi.

Kata kunci: Tekanan, tantrum, sawan, kanak-kanak autisma, panik

1.0 INTRODUCTION

The term "stress" refers to the physical reaction of a person in response to an unpleasant/dangerous environmental condition or stimuli as proposed by Selye (1956) [1] (Figure 1). Besides, over-stress has proven to be one of the major factors contributing to several serious health problems such as high blood pressure, panic attacks etc. On the other hand, autism spectrum disorder (ASD) is a generalized term for multiple complex disorders that share common symptoms, such as poor communication skills and lack of social interaction. Autism is a neuro-biological disorder which is often characterized by repetitive behavior, lack of communication skills and poor social interaction [2, 3]. It is a developmental disability affecting almost 1.5 million people in the United States [2]. Various case studies show that autism patients experience extreme tantrum behaviors, sleep difficulties, poor fine and gross motor skills [4, 5]. Moreover, autistic children experience seizures and tantrums when under a certain amount of stress. However, before any attack there are no visible signs or symptoms for the parent or guardian to identify whether or not the child is under stress.

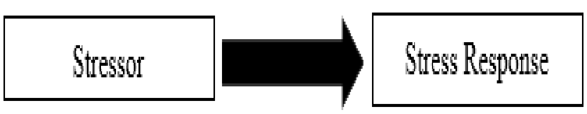


Figure 1 Stress response to a stressor (stimuli)

According to Bakker [6], stress is classified into three types such as, *acute stress, episodic acute stress* and *chronic stress* [7, 8]. Acute stress and episodic acute stress are not harmful as they last for a short period, making people anxious and frightened. However, these two types are easily curable [7, 8]. On the other hand, the chronic stress lasts longer than the two aforementioned types of stress. It causes serious complications depending on the patients [7, 8]. Evidently, in this condition stress-response hormones are some commonly known mental disorders like depression and anxiety[7].

These days a greater number of people are surviving stress, but, the type of stress dealt with in the present study and complications caused by it are restricted to a particular group of people i.e. autistic children. Behnam [9], claims that every 1 in 166 births suffers from Autism Spectrum Disorder [9]. secreted such as epinephrine, norepinephrine and cortisol which can add to factors causing cardiac abnormalities [10] along with some other dangerous complications. Moreover, high levels of stress can cause some well-known psychological disorders such as anxiety and depression.

Autistic children may have seizures, panic attacks; they may attempt suicide, homicide and can also be harmful to their surroundings while they are under stress. According to a study, autism disorder can be a result of abnormal brain development in utero caused by stress[11]. Currently, there is no commercial device for detecting stress. However, devices to explicitly monitor temperature, heart rate and variations in respiration exist. Nonetheless, even such high-end devices are devoid of detecting stress. For instance heart rate variation alone cannot discover stress. Hence, there is a need for a stand-alone device that can identify stress with the help of some physiological signals by processing them further in order to decide whether or not the person is under stress. Therefore, the system proposed in this research can non-invasively detect stress levels in autistic children through physiological signals such as skin perspiration and heart rate measured with the help of electronic sensors.

The present research is organized as follows: Section 1.0 describes the basics of autism disorder, stress, types of stress and effects of stress on autistic children. Later, section 2.0 elaborates the background of research and literature review focuses techniques, experimental setup, results and drawbacks found in previously built devices for stress detection purpose. However, section 3.0 briefs the methodology of interfacing the sensors, designing output display along with an indicator and designing of decision-making module. Furthermore, the section 4.0 presents the results obtained from the developed stress detection prototype and the problems faced during this research are also part of the very section. Finally, the last section 5.0 concludes the entire research and makes recommendation for further studies in this area of research.

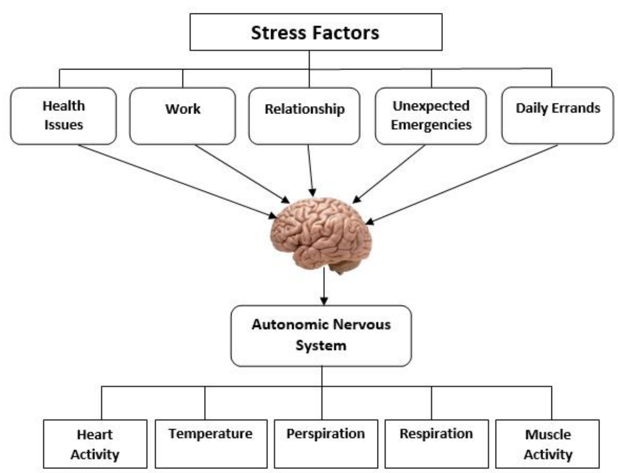


Figure 2 The reaction to stress factors is governed by ANS

2.0 LITERATURE REVIEW

2.1 Background

Stress is often overlooked; if chronic it can cause serious health complications, like, hypertension, cardiovascular diseases, diabetes, asthma and depression [12, 13].

The physical symptoms of stress are caused by autonomic nervous system (ANS). It regulates the body's main physiological activities, including the heart's electrical activity, respiration, gland secretion and temperature as shown in Figure 2.

Autistic children can have epileptic episodes when under stress [9]. For autistic children various devices and techniques are commercially available for instance; Isha Goel and Dilip Kumar (2014) developed an android based wearable smart locator band for people with autism, dementia and Alzheimer which can help track the exact location of such patients remotely [14]. Samsung also created a mobile application named "look at me" which can help children with autism to make eye contact. Another technique called Autism ID card, helps autistic people explain their medical condition to others in case of emergency. In 2010, MIT technology review also presented a device developed by *affectiva* that measures changes in electrodermal activity to detect stress. It was available for around $2000, but electro-dermal activity alone cannot detect stress accurately. Therefore, there is no commercial and economical device so far to detect stress in autistic children. This research explicitly focuses on developing a device for detecting stress in children suffering from autism.

2.2 Sensors

According to research, multiple sensors are found to be used for measuring stress in humans, noninvasively. Among them, a few most commonly used sensors are enlisted.

2.2.1 Galvanic Skin Response (GSR)

Galvanic Skin Response is the measure of changes in electrodermal activity due to stress or any other factor**.** This reading indicates the response of ANS to stress as a function of sweat glands. A GSR sensor by grove is shown in Figure 3(a).

2.2.2 Pulse Sensor/Blood Volume Pulse

Pulse sensor or BVP sensor makes use of photoplethysmography (PPG) technique, which noninvasively detects changes in blood volume. Its applications include measuring blood pressure, cardiac output and oxygen saturation. A pulse sensor is shown in Figure 3(b).

2.2.3 Temperature Sensor

Temperature sensors have a wide range of application in medicine, for instance; monitoring blood temperature, digital thermometers, organ transplant temperature monitor, and control. A temperature sensor, LM35 is shown in Figure 3(c).

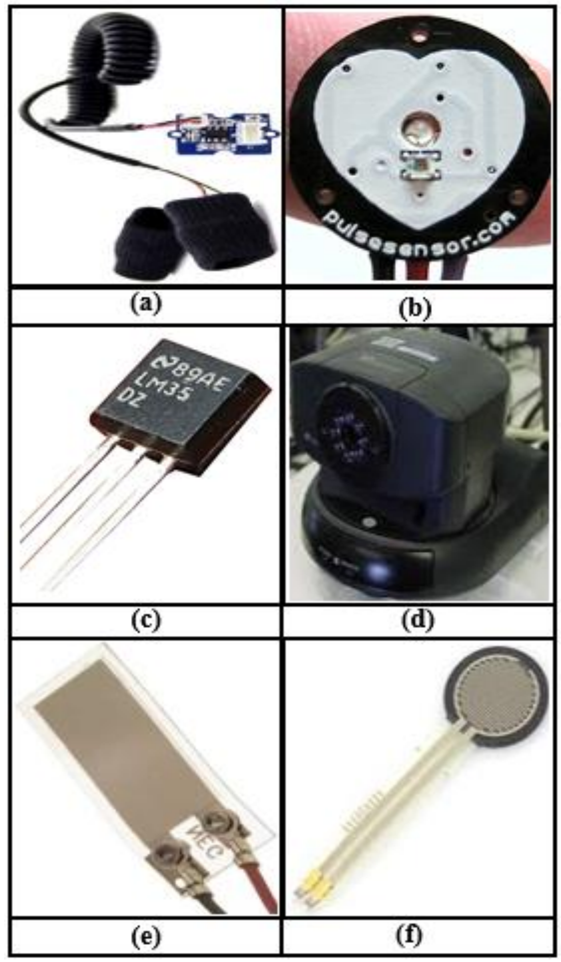


Figure 3 Commonly used sensors in stress detection system

2.2.4 ASL 504 Eye-Gaze Tracking Sensor

An eye tracker is a technique used to detect eye movement or eye position. It has various applications in medicine such as automotive and defense but in terms of stress detection, it is used to detect variations in pupil diameter. It is shown in Figure 3(d).

2.2.5 Piezoelectric Film Sensor

Piezoelectric film sensor is cheap and highly reliable sensor. It is strong and made of a flexible plastic allowing it to be suitable for various medical applications. In stress detection, it helps measure rate of respiration. It is shown in Figure 3(e).

2.2.6 Force Sensor

The force sensor shown in Figure 3(f), is also known as force-sensing resistor. It is a device used to measure the amount of force applied on it. In a research by Mohammad S. Sharawi [15], he used force sensor to measure the pressure applied by human tip.

2.3 Related Literature

In a research by J. Wijsman used wireless chest belt and hand sensor for detecting stress. The chest belt consisted of piezoelectric film sensors and gel electrodes for measuring electrocardiogram (ECG) and respiration whereas the hand sensor was to measure skin conductance. Bayes and k-Nearest Neighbors (k-NN) classifiers were used as decision-making modules. However, the drawback of this method is that the chest belt cannot be worn all the time, as it is uncomfortable [12]. Alberto de Santos Sierra, I-330-C2 PHYSIOLAB device by J & J Engineering measures skin conductance and heart rate variations. Fuzzy logic was used as a decision-making technique to decide whether the person is under stress or not. This method is inefficient because the device used for measuring signals can only be used by trained professionals and not by ordinary people [16, 17]. Jing Zhai used Eye gaze tracking system (ASL-504) for measuring pupil diameter, GSR sensors for measuring skin conductance and BVP sensors for measuring blood volume pulse but this device is also neither wearable nor portable. In this research, support vector machines were used for decision-making [18].

Madhuri [19] used a fuzzy influenced system as a decision-making module in her research. The respective electronic sensors helped measure blood pressure, heart rate variations, skin conductance and body temperature. The accuracy found was good but it is still a software based computing technique [13].

Sun [20] used the accelerometer, GSR and ECG signals to measure the physiological signals. The researcher obtained an electrocardiogram (ECG), galvanic skin response (GSR) and accelerometer data. The measured stress is during three daily common activities namely sitting, standing and walking which do not qualify as suitable conditions for measuring stress. Bayes net, SVM and decision tree were used.

David Carneiro acquired the information regarding touch pattern, touch accuracy, touch intensity, touch duration and the amount of movement for detecting stress levels. He designed an android app to use a stressor. He classified the data as training data and real data [1].

This research uses fuzzy-logic technique to detect stress as it showed the highest levels of accuracy in previous researches by A. Santos [16] and V.J. Madhuri [19]. The summary of related literature is shown in Table 1.

Table 1 Summary of literature work

Researchers	Physiological Signals	Sensor/Device	Decision-Making Technique
J. Wijsman [12]	Heart Rate & Respiration	Wireless Chest Belt consisting of Piezoelectric Film Sensors & Gel Electrodes	Bayes & K-Nearest Neighbor
A. De Santos Sierra [16]	Skin conductance & Heart Rate	I-330-C2 PHYSIOLAB	Fuzzy Logic
J. Zhai [18]	Pupil Diameter, Skin Conductance & Heart Rate	Eye gaze tracking system (ASL-504), GSR sensor & BVP Sensor	Support Vector Machine
V. J. Madhuri [19]	Blood Pressure, Heart rate, Skin conductance & Body Temperature	GSR Sensor, ECG, BP Machine, Temperature Sensor	Fuzzy Logic
Sun, F.T [20]	Skin Conductance, Heart Rate Variations & Movement data	Accelerometer, GSR Sensor & ECG	Bayes net, SVM & Decision Tree
David Carneiro [1]	Touch Pattern, Touch Accuracy, Touch Intensity, Touch Duration &Amount of Movement	Touch Screen. Video Camera & Accelerometer	Mann-Whitney Test

3.0 RESEARCH METHODOLOGY

3.1 Full Hardware Setup

The prototype consists of two sensors namely: pulse sensor and GSR sensor, an Arduino board having ATMega2560 microcontroller, LEDs as indicators, and an LCD display. The working of the system is in a manner that the data obtained from the sensors is fed to the microcontroller. The microcontroller further processes the data in a fuzzy-logic module which is already programmed in the microcontroller to detect the accurate levels of stress.

The reason behind choosing the fuzzy-logic technique is because it showed the highest accuracy level in previously built stress detection devices [16, 19]. The output from the fuzzy-logic module will be displayed on the LCD display and LEDs which are connected at the output of the arduino. The LCD display will show the output levels of stress in numerical form whereas the LEDs will light up in accordance to the level of stress, for instance, green LED for low stress, Yellow LED for medium stress and red LED for high stress. The flow chart for the system is shown in Figure 4.

3.2 Data Collection

The number of subjects participated in the experiment was 35, among which 19 were male and 16 were female. The experimental setup for the data collection part was developed based on the research of Carneiro [1]. An arithmetic game was developed that can challenge subjects mentally and emotionally in order to raise their stress levels to a certain point so that they show physiological symptoms which can be captured by the system. In this game, the subject performs mental calculations using four basic arithmetic operations on a few random numbers. The goal was to achieve the result as close as possible or equal to the given target number. For the experiment to be performed, the pulse sensor was attached to the index finger and the GSR electrodes were attached to the middle and ring fingers of the subject respectively.

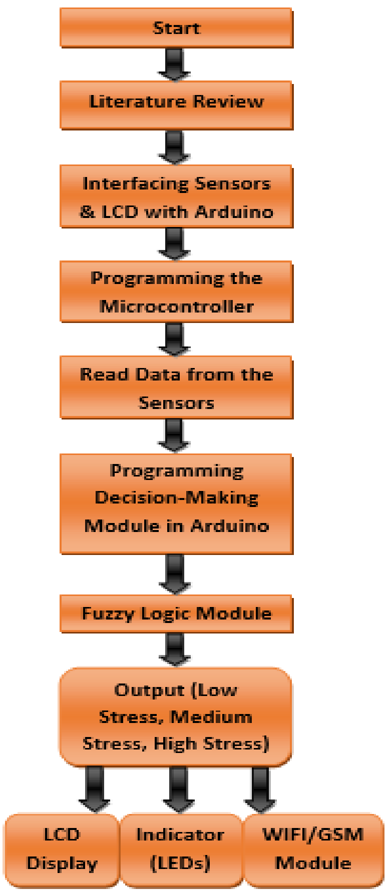


Figure 4 Flow chart of the system

The experiment was divided into three phase named as P1 – Low-stress phase or training phase, P2 – Medium- stress phase and P3 – High-stress phase. In P1, the subjects were asked to sit in a calm environment with no sounds or any kind of stressors and the sensor readings were recorded. In P2, the subjects were provided with a paper with five (5) arithmetic problems printed on it. The subjects were asked to solve the problems without any time limit. While subjects were solving the problems, the sensor data was recorded. In P3, the subjects were given another paper with five more arithmetic problems with an increased difficulty level along with a time limit of two (2) minutes. After that, all the subjects were provided with a questionnaire with routine questions asked by various psychologists.

The entire data collection was performed under the supervision of a medical professional and in a controlled environment. The final prototype is shown in Figure 5, whereas Table 2 shows the Arduino pin connections with the sensors and LCD.

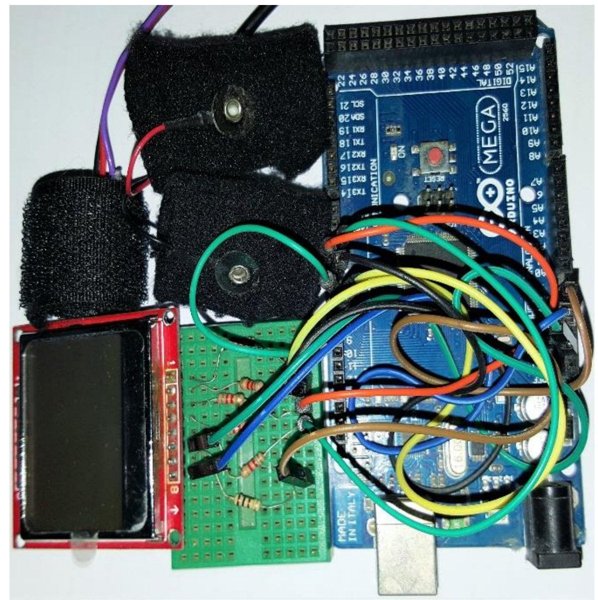


Figure 5 Final Prototype of vital signs monitoring system

Table 2 Arduino pin connections with sensor and LCD

A0 (Arduino Board)	GSR
A1 (Arduino Board)	Pulse
D3 (Arduino Board)	Pin 5 (LCD Module)
D4 (Arduino Board)	Pin 4 (LCD Module)
D5 (Arduino Board)	Pin 3 (LCD Module)
D6 (Arduino Board)	Pin 1 (LCD Module)
D7 (Arduino Board)	Pin 2 (LCD Module)
3.3V (Arduino Board)	Pin 6 (LCD Module)
GND (Arduino Board)	Pin 7 (LCD Module)
GND (Arduino Board)	Pin 8 (LCD Module)

4.0 RESULTS & DISCUSSIONS

This section presents the results of stress levels obtained from the developed system. The working of the prototype on a subject is shown in Figure 6. The results are given in a graphical manner categorized as stress in males and stress in females.

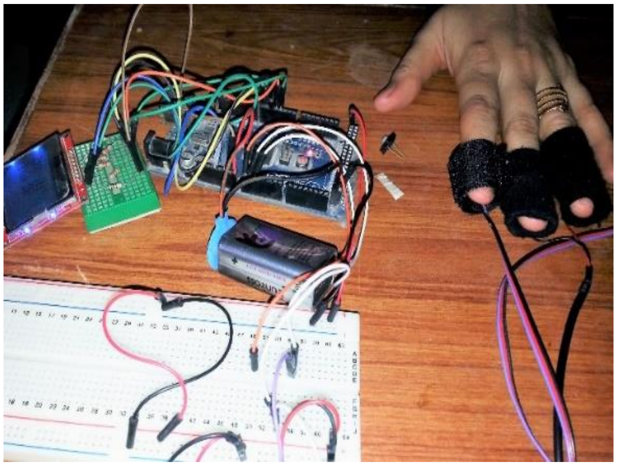


Figure 6 Testing of prototype on real subject

The graph for stress in males is shown in Figures 7(a) and for stress in females is shown in Figure 7(b). As depicted in the graphs, the level of stress increased exponentially with the phases. In phase P-1, the subjects show a lower stress level. For P-2, the stress level rises as it required mental calculations to be performed. Finally, in P-3, the subjects showed a noteworthy increase in stress levels because this phase included time-limit. This experiment also highlighted that the stress neither depends upon age of the subject. Stress is only affected by unpleasant external stimuli and any underlying medical condition. Though, there is a slight difference in stress levels of males and females i.e. stress levels in females are higher as compared to males.

Furthermore, this research also tested a temperature sensor, LM35 which did not show any significant results, proving that stress has no prominent impact on body temperature.

5.0 CONCLUSION

The system proposed in this research is able to monitor stress levels efficiently by making use of only two physiological signals i.e. heart rate and skin conductance. This system can be a useful tool for medical professionals in order to track the stress variations in autistic children non-invasively as this system has the ability to detect even the slightest change in stress levels.

Furthermore, in the future, the size of the system can be reduced to a level that it can fit in a watch, a wrist band or some other wearable device that can track the stress levels conveniently and efficiently. Along with that, a few more physiological signals can be studied and implemented to increase the accuracy level.

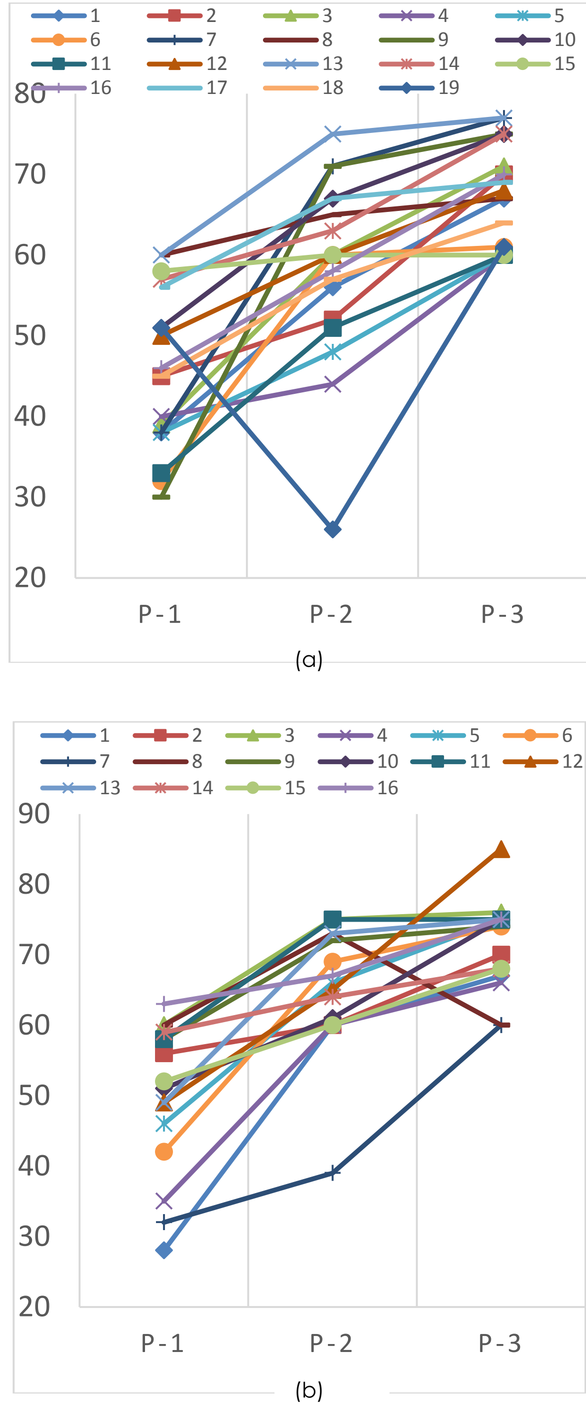


Figure 7 Stress level in: (a) males, and (b) females

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