Evolution in Electrical and Electronic Engineering Vol. 2 No. 2 (2021) 248-255

EEEE

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/eeee
e-ISSN : 2756-8458

Development of Multiple Bio-Signals Microcontroller-based Wearable Device for Human Stress Monitoring Application

Aminatul Saadiah Jumaat Ali[1], **Latifah Abdullah**[1], **Zarina Tukiran**[1,2]*, **Nurulhuda Ismail**[1]

[1]Department of Electronic Engineering, Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

[2]Internet of Things (IoT) Research Group, Faculty of Electrical and Electronic Engineering,
Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/eeee.2021.02.02.030
Received 04 July 2021; Accepted 25 August 2021; Available online 30 October 2021

Abstract: Stress is inevitable, however, overstress needs to be managed before affects a person's health. One way to monitor a person's stress is by evaluating the body bio-signals and heart rate is the most common approach. In the market, various wearable devices measured only heart rate – which might contribute to a false alarm. This work is an attempt to develop a wearable device that can measure stress based on two bio-signals; heart rate and skin conductance. In this work, the photoplethysmography (PPG) sensor and Galvanic Skin Response (GSR) sensor are used to measure the heart rate and skin conductance, respectively. Then, the ATmega328P microcontroller process the data and display the output of "Not Stressed" or "Stressed" on the LCD. There are two experiments; (i) analyse the accuracy of sensor measurement and (ii) evaluate the overall performance of the prototype. The first experiment concludes there is an insignificant different measurement for the PPG sensor when compared to the commercial heart rate application. For the second experiment, the findings from four adult healthy subjects conclude the device able to produce the correct output as expected.

Keywords: Bio-signals, Heart Rate, Skin Conductance, Stress Detection, Wearable

1. Introduction

Stress is a response of body pressure that is triggered when the person experiences something new, unexpected or that threatens their sense of self. Sometimes, the stress response can be useful as it helps to push through fear or pain. Though, too much stress can cause negative effects that cause a permanent

Corresponding author: zarin@uthm.edu.my

stage of fight or flight [1]. The pressure for accomplishing the goal may cause mental illness, such as depression, anxiety disorder, mood disorder, and personality disorder. A study by National Health and Morbidity Survey 2019 reported that 500,000 Malaysian suffer from depression and 108,919 were young Malaysian aged 15 to 24 years old. One of the reasons is because youths were more likely to get depression from the stress of academic and social struggles [2]. With so many high achievers, young adults need to compete for being accepted into society. Lack of attention from family support leads young generations to develop poor trust with their surroundings and get depressed because they could not ask for help. It concludes that the rate of young generations having mental health is still higher in Malaysia. Conversely, asking for help from a trusted person might overcome all of those life struggles [3].

As stress is linked to mental disease, its treatment varies and there is no specific medicine. It can, however, be avoided by managing stress before it harms our biological health. Stress can be discovered by evaluating biochemical impacts on our bodies, according to researchers [4]. One of the best ways is by heart rate monitoring as used by several wearable devices [5]–[7]. The time interval between one peak of a heartbeat and the next peak of a heartbeat is used to calculate heart rate variability (HRV). An electrocardiogram (ECG) is used to measure the peak of a heartbeat and can be obtained from the waves of Q, R, and S; commonly known as QRS complex in an ECG signal. Using only one type of bio-signal may cause less accuracy of the device and yet all the devices can only be monitored by a single recipient.

In this work, two bio-signals activities; heart rate and skin conductance are used as inputs. This is due to these two signals are suitable for wearable devices and their variation is strongly related to stress stimuli [8]– [11]. Therefore, this paper is organised as follows. Section 2 discusses the methodology, Section 3 explains the results and discussion, followed by a conclusion in the last section.

2. Methodology

As illustrated in Figure 1, the wearable device is composed of an ATmega328P-based microcontroller board, XD-58C pulse sensor, LM 324 grove galvanic skin response (GSR) sensor, 5-volt lithium battery, and 20x4 Liquid Crystal Display (LCD). The system uses the pulse sensor and GSR sensor to sense and measure heart rate, and skin conductance, respectively. The microcontroller is used to process the sensor data and determine the output. The LCD shows the sensor's data and output.

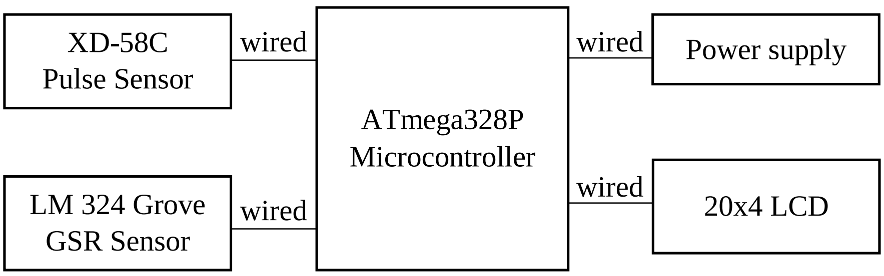


Figure 1: Block diagram

2.1 Hardware Configuration between Components and Microcontroller board

The hardware configuration involves configuration between sensors, microcontroller board, and output device. Figure 2 shows the physical connection between components and microcontroller and the I/O pin assignment is shown in Table 1.

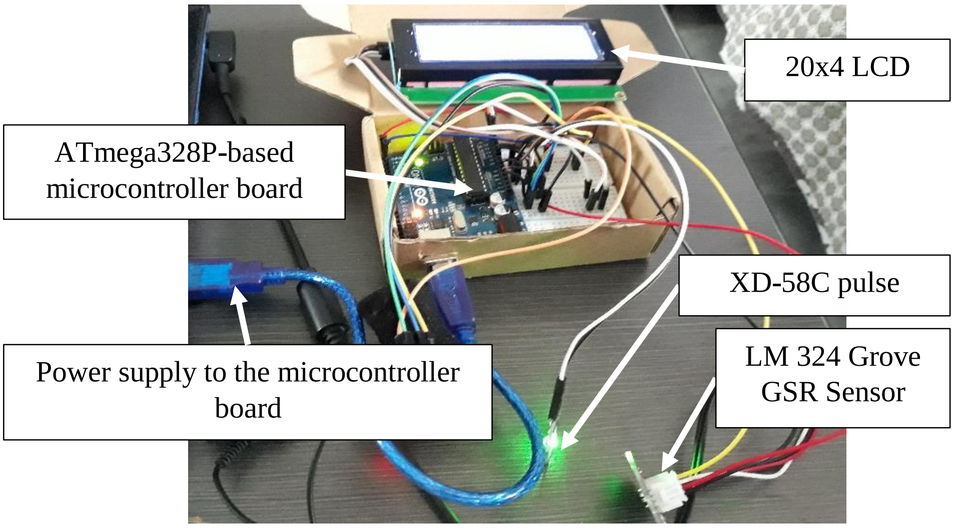


Figure 2: Physical connection between components and microcontroller board

Table 1: I/O pin assignments

I/O Pin of Microcontroller	Description
1, 4, 7	GND
2	VCC of Pulse Sensor
3	Output of Pulse Sensor
6	VCC of GSR Sensor
5	Output signal of GSR Sensor
12	VCC of LCD
13	SCA of LCD
14	SCL of LCD

2.2 Stress Detection Rules

In this work, the rules for stress detection are formulated according to [12]–[15]. During rest, the typical heart rate and skin conductance are ranging from 60 to 100 bpm [12]–[14] and 2 to 20 μS [15], respectively, for an adult. Table 2 summarises the rules imply for stress detection.

Table 2: Rules for Stress Detection

Rule No.	Description
1.	IF Heart Rate is *unrest and* Skin Conductance is *unrest*, THEN output is "Stressed".
2.	Otherwise, the output is "Not Stressed".

Note: Heart Rate in rest is 60 to 100 bpm, Skin Conductance in rest is 2 to 20 μS

3. Results and Discussion

This section is divided into three (3) sections; (i) the prototype and (ii) the accuracy performance of heart rate sensor measurement, and (iii) the overall performance of the prototype.

3.1 Prototype

Figure 3 shows the prototype of the device. The device works by placing three fingers on the sensors; two fingers are placed on the GSR sensor whilst another finger is placed on the pulse sensor to obtain the results of Figure 4(a)-(f).

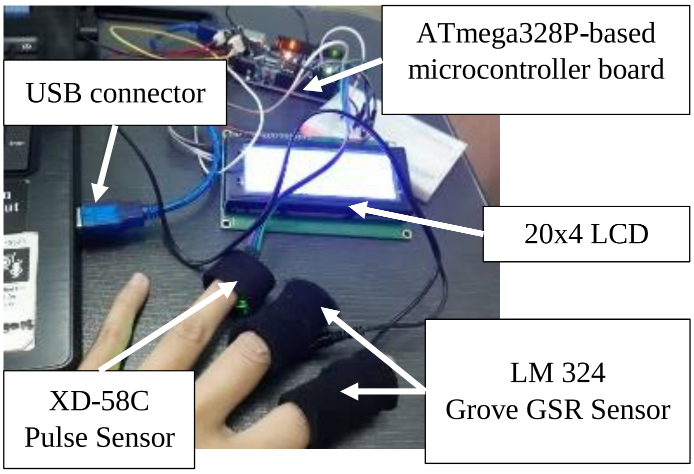


Figure 3: The prototype

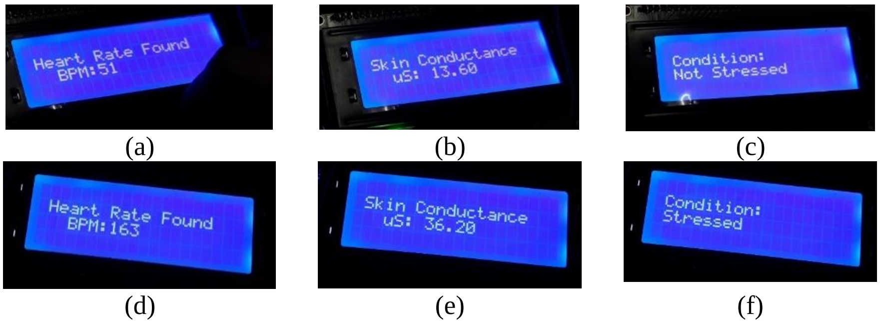


Figure 4: Display on LCD for (a),(d) heart rate reading, (b),(e) GSR reading, and (c),(f) output of the body state

3.2 Accuracy Performance of the Heart Rate Sensor Measurement

In order to determine the accuracy of heart rate sensor measurement, a commercial application namely *Samsung Health* in a smartphone Samsung Note 4 is used. The application measures heart rate in beats per minute (bpm) using an optical LED light source and an LED light sensor [14].

In this experiment, the heart rate from the prototype is strapped on one finger using Velcro. Another finger has touched the sensor at the back of the smartphone. The experiment is divided into separate phases, as illustrated in Figure 5. Each experiment consists of one minute of relaxation and one minute of a stress-inducing task (SiT). Prior to the relaxation phase, a stabilization period is established by the subject.

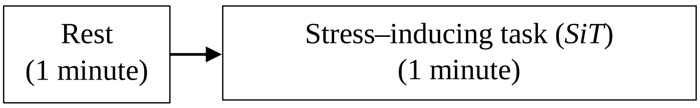


Figure 5: Experiment protocol

Heart rate measurements from both devices are acquired throughout the phases simultaneously. For data collection, the prototype is connected via a USB port to the computer for streaming the measurement data to the Integrated Design Environment (IDE) software. Whereas the commercial application shows the measurement data every 20 seconds on the smartphone screen. Both heart rate measurements are collected manually to save them in the CSV format. Then, since the application only shows measurement at a certain time, therefore, timestamps from both measurements are compared to extract the prototype’s measurement data before computing the average.

As tabulated in Table 3, when compared with the heart rate measurement by the commercial application, the average measurement by the PPG sensor of the prototype differs approximately 0.7 bpm and 1 bpm during the *rest* and *SiT* phase, respectively.

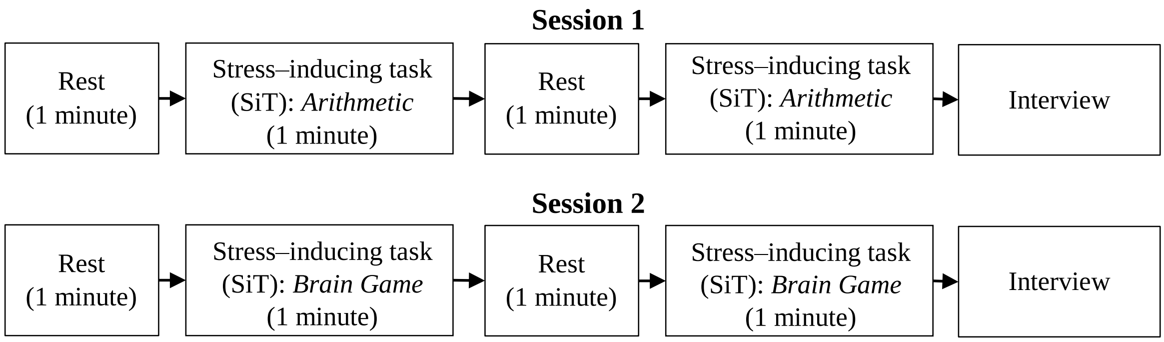
Table 3: Comparison of heart rate measurement by the prototype and commercial application

	Average heart rate measurement (bpm)		**Diff = *a-p* (bpm)**
Phase	by application, *a*	by prototype, *p*	
Rest	87.667	87	0.667
SiT	87	86	1

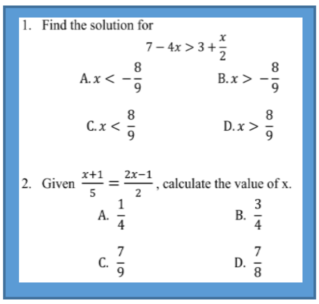
Note: *Rest* phase – The subject was seated on the chair and take a deep breath. *SiT* phase – The subject was still seated on the chair and performed arithmetic exercises.

3.3 Overall Performance of the Prototype

There are two sessions; (i) *session 1 – arithmetic task*, and (ii) *session 2 – brain game* as shown in Figure 6a. The questions of session 1 and session 2 are shown in Figures 6b and 6c, respectively. In this experiment, four healthy adult subjects were recruited after obtaining their consent. The sensors from the prototype were strapped on the subject's three-finger using Velcro as shown in Figure 3. The data collection for the prototype was set up as in section 3.2. Data were collected only one time for each phase of the sessions.



(a)



(b)

(c)

Figure 6: (a) Experiment protocol and questions in (b) arithmetic and (c) brain game

The experiment of session 1 and session 2 allow the prototype to produce the expected output as designed in Table 2. Table 4 shows a sample of experimental results taken from *SiT* phase of session 1. The results of the *rest* phase were excluded from the table due to the "not stressed" output for all measurements.

Table 4: Sample of experimental results of heart rate (HR) and skin conductance (SC) measurement and its output on LCD for the first and second *SiT* phase of Session 1

			No. of measurement														
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Subject#1	**1st *SiT***	**HR**	121	104	106	102	147	85	87	102	101	101	105	110	102	101	100
		SC	9	8	8	8	9	8	8	8	7	7	7	7	7	7	7
		LCD	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
	2nd *SiT*	**HR**	188	89	89	105	119	109	94	76	70	92	97	89	100	93	98
		SC	10	9	9	10	10	9	9	9	9	9	8	8	8	8	8
		LCD	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
Subject#2	**1st *SiT***	**HR**	95	140	123	139	83	87	78	86	78	185	77	80	69	76	79
		SC	14	14	14	15	15	16	12	13	12	11	11	12	13	14	14
		LCD	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
	2nd *SiT*	**HR**	68	108	109	78	76	118	95	150	158	111	96	77	88	150	136
		SC	4	39	39	4	4	24	4	8	9	8	3	3	3	25	22
		LCD	*N*	***S***	***S***	*N*	*N*	***S***	*N*	*N*	*N*	*N*	*N*	*N*	*N*	***S***	***S***
Subject#3	**1st *SiT***	**HR**	101	111	94	98	80	160	138	86	147	138	87	105	102	133	115
		SC	12	12	14	12	13	12	12	14	23	22	12	15	19	21	20
		LCD	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	***S***	***S***	*N*	*N*	*N*	***S***	*N*
	2nd *SiT*	**HR**	75	75	91	90	88	90	119	118	86	100	81	82	178	127	96
		SC	10	10	13	13	13	22	22	23	10	15	12	11	20	20	13
		LCD	*N*	*N*	*N*	*N*	*N*	***S***	***S***	***S***	*N*	*N*	*N*	*N*	***S***	***S***	*N*
Subject#4	**1st *SiT***	**HR**	135	136	135	123	121	106	83	86	84	95	131	127	99	91	82
		SC	24	23	20	20	18	17	16	16	17	17	19	19	12	12	13
		LCD	***S***	***S***	***S***	***S***	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*	*N*
	2nd *SiT*	**HR**	85	112	108	94	82	95	147	181	138	116	80	85	84	83	188
		SC	14	17	16	15	15	15	18	21	21	20	15	14	13	13	15
		LCD	*N*	*N*	*N*	*N*	*N*	*N*	*N*	***S***	***S***	*N*	*N*	*N*	*N*	*N*	*N*

Note: The red cell represents the measurement exceeded the rest value of the heart rate and/or skin conductance. The green cell represents the measurement of the heart rate and/or skin conductance is in the rest state. *N* and *S* represent *"Not Stressed"* and *"Stressed"*, respectively.

Table 5 and Table 6 show the average measurement of HR and SC from four subjects for session 1 and session 2, respectively. The average value is used to represent a collection of 15 data measurements of heart rate and skin conductance for each subject.

Table 5: Average measurement of HR and SC of Session 1

Subject	***1st Rest***		***1st SiT***		***2nd Rest***		***2nd SiT***	
	Average HR	Average SC	Average HR	Average SC	Average HR	Average SC	Average HR	Average SC
Subject#1	77.53	7.83	104.93	7.54	84.40	7.29	100.53	8.82
Subject#2	71.00	13.27	98.33	13.27	80.60	8.43	107.87	13.29
Subject#3	86.47	8.22	113.00	15.55	91.20	12.20	99.73	15.21
Subject#4	70.87	8.19	108.93	17.63	74.27	8.82	111.87	16.16

In Table 5, the average value for heart rate when the subject was in the *SiT* phase is higher when they were in the *Rest* phase for both measurements. It also shows when the 1st *SiT* phase was conducted, the results of heart rate for Subject#1 and Subject#3 are higher compared to the 2nd *SiT* phase. In the interview, the subjects responded they were at ease when they got familiar with the situation and the difficulty of question#2 is lesser than question#1.

Table 6: Average measurement of HR and SC of Session 2

Subject	***1st Rest***		***1st SiT***		***2nd Rest***		***2nd SiT***	
	Average HR	Average SC	Average HR	Average SC	Average HR	Average SC	Average HR	Average SC
Subject#1	74.20	5.78	95.53	13.17	68.60	4.76	87.00	7.54
Subject#2	74.73	12.86	94.87	12.61	74.87	7.91	93.60	12.68
Subject#3	81.80	7.75	98.27	15.06	74.87	7.91	88.27	13.56
Subject#4	69.40	7.69	93.93	15.07	72.47	7.95	90.33	14.34

Similar to Table 6, the average value for heart rate when the subject was in the *SiT* stage is higher when they were in the *Rest* stage. In addition, Table 6 shows when the *1st SiT* stage was conducted, the heart rate and skin conductance of all subjects are higher compared to the *2nd SiT s*tage. Respond from all subjects during the interview, the difficulty level of question in Session2 is lesser compared with the questions in Session1.

4. Conclusion

In conclusion, this work describes the development of a wearable device that can measure stress based on two bio-signals; heart rate and skin conductance. Two sensors were used, the PPG and GCR to measure the heart rate and skin conductance, respectively. The ATmega328P processes the data and displays the output of “Not Stressed” or “Stressed” on the LCD. The experimental findings show the accuracy of measurement by the PPG sensor is at par with commercial application Also. the developed prototype is able to produce the correct output as expected. It is expected in near future, the output produced by the prototype will be able to be sent to the third user as a notification.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for the support of this work.

References

[1] “Stress,” Mental Health Foundation, March 26, 2021. [Online]. Available: https://www.mentalhealth.org.uk/a-to-z/s/stress [Accessed May 22, 2020]

[2] F. Kwan, “15 to 24-year-olds among those affected by depression,” Free Malaysia Today (FMT), November 5, 2020. [Online]. Available: https://www.freemalaysiatoday.com/category/nation/2020/11/05/15-to-24-year-olds-among-those-affected-by-depression/ [Accessed May 10, 2021]

[3] N. Badarudin, “Tackling mental health issues in young people: New Straits Times,” NST Online, January 23, 2018. [Online]. Available: https://www.nst.com.my/lifestyle/heal/2018/01/327953/tackling-mental-health-issues-young-people [Accessed May 10, 2021]

[4] A. P.Allen, P. J. Kennedy, J. F. Cryan, T. G. Dinan, and G. Clarke, "Biological and psychological markers of stress in humans: focus on the Trier social stress test," Neuroscience and biobehavioral reviews, vol. 38, pp. 94–124, 2014, DOI: 10.1016/j.neubiorev.2013.11.005

[5] "Lief: Smart patch that fights stress," Kickstarter, October 1, 2019. [Online]. Available:https://www.kickstarter.com/projects/getlief/lief-smart-patch-that-fightsstress [Accessed 24 October 2020]

[6] D. D. Rosario, "Olive: Stress-managing bracelet," Stylus, October 15, 2014. [Online]. Available: https://www.stylus.com/yypcnq [Accessed October 24, 2020]

[7] M. Sawh, "Stress wearables: best devices that monitor stress and how they work," Wearable, April 6, 2020. [Online]. Available: https://www.wareable.com/health-and-wellbeing/stress-monitoring-wearables-explained-7969#stress [Accessed May 23, 2020]

[8] S. Akella, H. Bandi and S. Bhagat, "Notification-enabled heart rate monitor using photoplethysmography and real-time moving averages," 2020 International Conference for Emerging Technology (INCET), pp. 1-4, 2020, DOI: 10.1109/INCET49848.2020.9154138.

[9] J. Park, J. Kim and S. Kim, "Prediction of daily mental stress levels using a wearable photoplethysmography sensor," TENCON 2018 - 2018 IEEE Region 10 Conference, pp. 1899-1902, 2018, DOI: 10.1109/TENCON.2018.86501

[10] R. F. Navea, P. J. Buenvenida, and C. D. Cruz, "Stress detection using galvanic skin response: An android application," Journal of Physics: Conference Series, International Conference on Biomedical Engineering (ICoBE), vol. 1327, August 2019, DOI: 10.1088/1742-6596/1372/1/012001

[11] A.S. Anusha, P. Sukumaran,V. Sarveswaran., S. S. Kumar, A. Shyam, J. A. Tony, S. P. Preejith, and S. Mohanasankar, "Electrodermal activity based pre-surgery stress detection using a wrist wearable," in IEEE Journal of Biomedical and Health Informatics, vol. 24, no. 1, pp. 92-100, Jan. 2020, DOI: 10.1109/JBHI.2019.2893222

[12] R. L. Edward, "What's a normal resting heart rate?", Mayo Foundation for Medical Education and Research (MFMER), October 2, 2020. [Online]. Available: https://www.mayoclinic.org/healthy-lifestyle/fitness/expert-answers/heart-rate/faq-20057979 [Accessed August 13, 2021]

[13] M. Markus, "What should my heart rate be?", Medical News Today, UK, January 19, 2021. [Online] Available: https://www.medicalnewstoday.com/articles/235710 [Accessed August 13, 2021]

[14] "Pulse & Heart Rate", Cleveland Clinic, Ohio, November 18, 2018. [Online]. Available: https://my.clevelandclinic.org/health/diagnostics/17402-pulse--heart-rate [Accessed August 13, 2021]

[15] E. D. Michael, M. S. Anne, L. F. Diane, The Electrodermal System in Cambridge Handbook of Psychophysiology, Cambridge University Press, 2016, pp. 224-225.