DEPARTMENT:

Computer Science and Engineering

FACULTY SPONSOR:

Dr. Michelle Mellenthin

STUDENT(S):

Bryn Loftness

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Constructing An Accessible Low-Budget Stress Detection Biosensor

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Constructing an Accessible Low-Budget Stress Detection BioSensor

Bryn Loftness
Colorado Mesa University
Dr. Michelle Mellenthin and Karl Castleton
bcloftness@mavs.coloradomesa.edu
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Abstract

Currently, biosensor research identifying stress through physiological responses is completed with state-of-the-art sensors comprised of high-quality and high-price materials. These projects are generating substantial results and noteworthy findings. However, replication and production of low-budget versions of these high-grade stress detection tools for use of the general public is lacking. This project aims to explore this gap through the development of a proof-of-concept device comprised of three economical, accessible sensors: a galvanic skin response (GSR) sensor for measuring electric resistance, an electromyography (EMG) sensor for measuring muscle stimulation, and a photoplethysmography (PPG) pulse sensor. Using this prototype device, pilot data of physical responses was collected and analyzed during exercise, which is a fundamental form of stress on the body.

1. Introduction

The use of sensors for improving the efficiency and productivity of daily life has been a large part of 21st century technology. Examples of this can be seen through the wide applications of biometric scanners for personal electronic device security[1], exercise tools such as Smart Watches for measuring physical activity[11], environmental sensors such as seismic monitors for early warnings for natural disasters[12], etc. Sensors tracking input data, whether it's how long the refrigerator has been open or how far a driver is from the curb when parking a car, have helped to define metrics that shape and cultivate a smarter environment that modern day humans thrive in.

Healthcare is one specific field where sensors have become increasingly popular. Biosensors, which are sensors specifically designed to measure biological aspects of the body or an environment, are used in a variety of applications tasked for improving the human condition and overall quality of life[4, 28]. The first biosensor to be invented is attributed to Leland C. Clark in 1956. He created a sensor used for oxygen detection, now called the Clark electrode[20]. While there was work prior to Clark in the fields of chemical analysis and electrode creation, Clark is known among many to be the true 'father of biosensors'[4]. The field of biosensor development has grown immensely since Clark's famous invention to an expansive multidisciplinary area that encompasses researchers, academics, and industry professionals in the fields of physics, chemistry, biology, and engineering[4].

One extension of biosensors is within the field of biofeedback. Applied biofeedback is a term used in clinical or research settings that encompasses the broad group of therapeutic procedures that utilize electronic or electromechanical instruments to measure, process, and deliver back to the user information relating to their bodily state. This is done with the overall goal to help the user develop a greater awareness and confidence within their influence over their own physiological processes[22].

In this work, we investigate the design of a low-cost stress management device. Since stress is a very complex process and varies widely across individuals, the diagnosis and treatment of stress could be improved by making it more subject-specific[4,23].

Stress is commonly defined as an internal or external stimulus evoking a biological response; it is known to be a trigger or aggravator for many diseases and pathological conditions[2]. Stress can cause problems with digestion, depression, memory or concentration, high blood pressure, and even heart disease or stroke in some cases[1,3,4]. To put this problem in perspective, the number one leading cause of death in the United States is heart disease with 647,457 deaths per year; The fifth leading cause of death are strokes taking 146,383 lives per year[5]. This shows that proper stress management is key to maintaining a healthy lifestyle.

In a resource published by the Mayo Clinic, it is stated that the first step of stress management is the individual identifying their triggers, such as specific environments or tasks[10]. However, in our modern fast-paced high-pressure society, this can be a real challenge. This leads people to seek external stress-reduction techniques that are less introspective such as tai chi, yoga, or being in nature to bring relief[10]. For many people, a device to track frequency and intensity of stressful moments could be useful in not only identifying stress but also help in determining which management strategies are most effective.

The market for technology-based approach to mindfulness is large, since need for improved self-care is great in today's fast-paced society. To be accessible to the general population, such devices such be low-cost and easy to use. Present on-the-market stress management devices can cost hundreds of dollars. Many are not feasible for wearing in daily life or only include one or two simple sensors[14-18]. In addition, these high cost biosensor stress-reduction devices are not widely used despite the need for improved stress management tools. Therefore, the design presented is a first step in addressing this need. The initial prototype incorporates multiple low-cost biosensors in order to determine their efficacy in detecting the physiological responses to stress.

2. Background

There have been several studies released regarding the monitoring of stress on the body using wearable sensors[21,24,30-34]. Many of the studies note that timely recognition of stress can help individuals because they can be presented with various coping strategies for managing the stress while it occurs or shortly afterwards. Some of the frequently monitored metrics relating to stress and sympathetic arousal include pulse rate, skin surface temperature, skin conductance, muscle stimulation, and heart rate variability[5].

Some studies measuring the effects of stress on heart rate use high cost materials, like ECG or EKG sensors[35]. However, it has been found that a more cost-effective, simple heart rate monitoring sensor, the photoplethysmography-based(PPG) pulse sensor, can also be effective in showing heart rate reactions to stress[25,26]. The same study showed that, when put into a trial of four different stress-inducing tasks— arithmetic, reaction time, cold pressor, and bicycling— the ECG and the PPG sensor rate values did not differ significantly, but the difference in heart rate between the activities themselves shown by both sensors did show a significant difference in reactivity[25]. This supports the theory that the collection of heart rate activity could be very beneficial for a stress monitoring device, especially if the device needed to differentiate from different types of stress[29].

Other studies have been conducted regarding the use of sweat as a non-invasive bio-indictor that could be used in a variety of settings[27, 19]. Perspiration and sweat measurement lie in the scope of EDA, electrodermal activity. EDA describes the fluctuations in the skins electrical conductance, also known as galvanic skin responses(GSR), that result from sympathetic activity[6]. Measuring skin conductance has shown to indicate states of emotional/autonomic arousal[7,8]. Therefore, tracking these electrodermal changes with a GSR sensor could also prove to contribute positively for a stress monitoring device.

A less commonly used sensor for stress detection is one that targets changes of the musculoskeletal system, an electromyography (EMG) sensor. Sudden onset of stress causes the muscles of the body to tense up all at once, as a part of the 'fight-or-flight' response. Chronic stress can cause the muscles in the body to be in a more consistent state of tightness[9]. The main areas for muscle tension caused by stress for many is the shoulder, neck, and head region. For these reasons, it is hypothesized that if muscle tenseness was tracked on an upper back muscle, such as the trapezius, that changes in this muscle caused by stress could be measured.

3. Methodology

There were many characteristics that were considered for the construction of the biosensor device. The main elements evaluated for the selection of sensors were sensitivity, reproducibility, stability, and cost. In order to create a device for stress-detection, the sensors selected needed to be sensitive enough to capture bodily fluctuations; those changes defined the difference between an aroused versus calm state. The sensors also needed to be consistent in their performance, and simple enough to be a reproducible, affordable design. The overall construction of the device also had to be able to withstand movement, shock, and sweat.

Taking these criteria into consideration, along with the need to measure sweat, heart rate, and muscle tenseness, the sensor of each of the following types were chosen: a galvanic skin response (GSR) sensor for measuring electrodermal activity, a photoplethysmography (PPG) pulse sensor for measuring heart rate variability, and an electromyography (EMG) sensor to measure muscle stimulation. The specific make and model of each selected sensor for the prototype can be found in Table 1. A similar device was proposed in [13]; however, it involves the use of an ECG rather than a PPG sensor. It also includes a respiration sensor in its device design. The design of our system is outlined in Figure 1.

Table 1. Make and Model of Components Selected for Prototype with Cost

Micro-controller	Galvanic Skin Response Sensor	Pulse Rate PPG Sensor	EMG Muscle Sensor
SparkFun ESP32 Thing Micro-controller (DEV-13907)	Grove – GSR Sensor V1.2	DFRobot Heart Rate Sensor (SEN0203, V1.0)	MyoWare 3-lead Muscle Sensor (AT-04-001) + MyoWare Cable Shield (DEV-14109)
$21.95	$10.10	$16.99	$37.95 + $4.95

The language used for the software of the device is a C-based language written within the Arduino IDE to connect with an ESP32-Thing Microcontroller. The devices current set-up requires a hard-wired connection from the ESP32 to a computer while collecting data. Data is outputted via a Serial Terminal on the connected computer in real-time while the user wears the biosensor device.

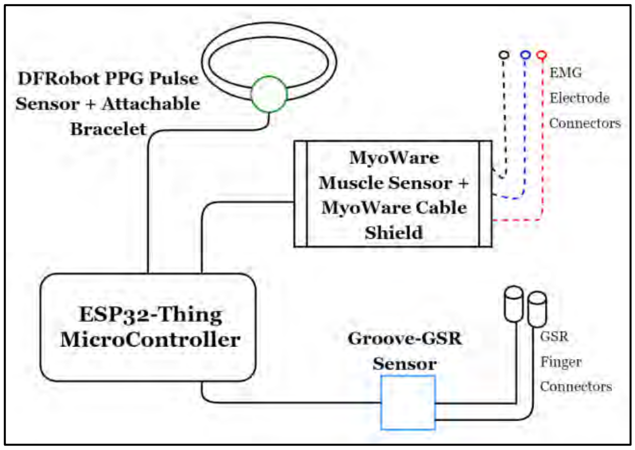

Figure 1. Schematic of Prototype

To evaluate the devices ability to show stress on the body, tests were done preliminarily with one volunteer subject. The GSR sensor was attached to the body via two cylindrical finger straps that both are placed on the same hand; one GSR electrode is inside each of the finger straps. The PPG sensor was placed via a bracelet strap to the wrist as shown in Figure 2. The EMG sensor electrodes were placed on the upper trapezius muscle on the back as shown in Figure 3. The black electrode was placed as a reference node, and the blue was placed at the end of the muscle, while the red was placed directly mid-muscle. All three sensors were wired to the ESP32 for power and instructions.

The test was designed in several parts. The first part was intended to mimic and measure stress on the body through a relaxed state. Then, stress was measured at a semi-heightened state, followed by a fully heightened state. The first trial was simply to capture a baseline stress level for the subject. The individual was measured for 2 minutes using the biosensor device during a relaxed state. Next, the subject was asked to do a 2-minute warm-up exercise activity of their choice. After the five minutes had passed, the subject was measured with the biosensor prototype device again for 2 minutes.

Once the post-warmup data was collected, the subject was asked to do a 4-minute rigorous workout of their choice. As soon as the 4 minutes had passed, the subject then was measured with the biosensor prototype device again for 2 minutes. A visual guide to the placement of the sensors on the subject can be seen in Figure 2 and 3.

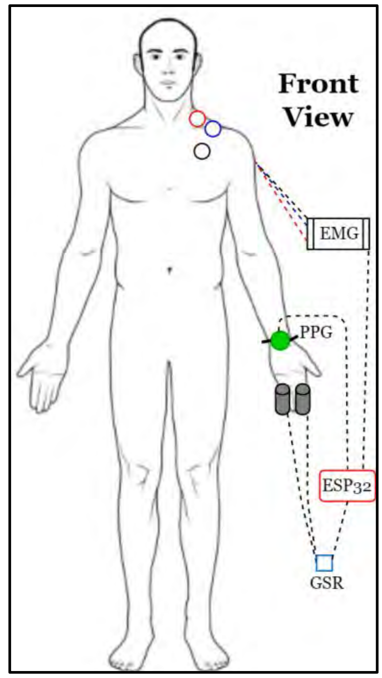

Figure 2. Front View of Sensor Placement

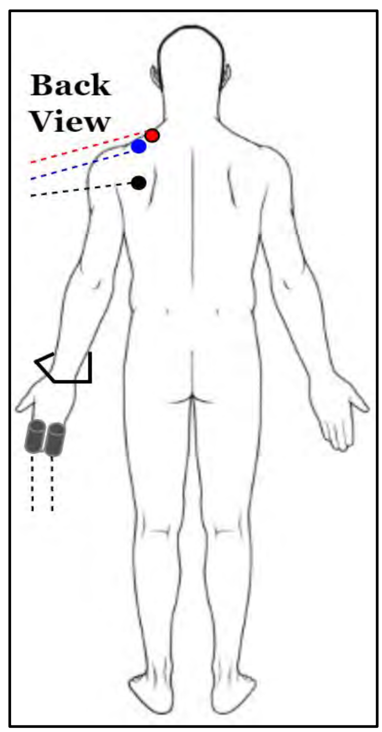

Figure 3. Back View of Sensor Placement

3. Results

We were able to collect good data on our healthy human volunteer. Raw data is shown from all 3 sensors in Figures 4-6. The subjects baseline values were recorded prior to any physical exertion, which can be seen in the values indicated "At Rest." After obtaining a baseline, the volunteer subject elected to do two minutes of body-weight squats in order to experience some level of stress. After the two minutes had passed, the subject was attached to the biosensor device and measurements were collected. This can be seen in the figures below indicated as "After 2 Minutes of Activity." Next, the subject was asked to do four minutes of rigorous activity. During this period the subject performed bodyweight squats and star-jumps. Promptly after the four minutes were up, the subject was connected to the biosensor device for data collection. These measurements can be identified on the figures below as "After 4 Minutes of Activity."

After the experiment was completed, the data from the three sensors were analyzed according to activity level. Figure 4 shows the PPG pulse rate sensor activity for the two-minute data collection period. The increases in heart rate after each trial are shown: from the resting state to the warm-up state, and then from the warm-up state to the fully heightened state. These increases in heart rate directly correlate with the level of activity. Although, the trends seem clear for all the sensors, it is possible that the quality of the PPG sensor data was affected due to the calibration time needed for consistent readings. This caused for lags in measurement timeliness. We hypothesize that during this time our volunteer may have been able to begin recovering. As shown in Figure 4, the heart rate measurement of the third trial – After 4 Minutes of Activity – was already decreasing for the user during the data collection period. Thus, further enforcing the need for a real-time device for most accurate real-time heart-rate readings.

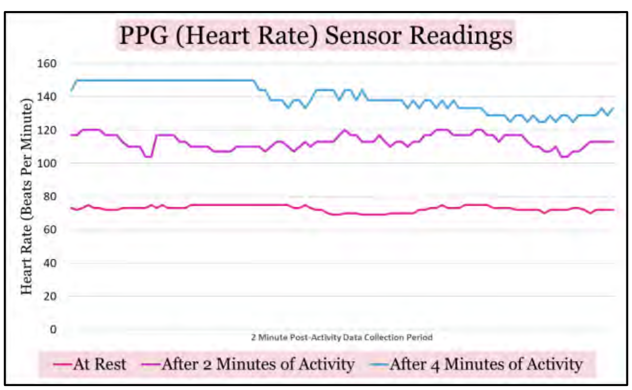

Figure 4. PPG Heart Rate Sensor Results

Next, we examined the results from the EMG sensor. There were some difficulties with the calibration of the EMG device during the collection of data after the second stage: after two minutes of activity. Due to these discrepancies, the data was omitted from the trial. In addition, the device readings had a significant amount of noise included. Before doing any analysis, all values greater than 1000 from the raw data input were omitted and attributed to noise or potential misplacement of electrode sensors on the trapezius muscle. For the EMG sensor to be most accurate, the three electrodes must be placed in very specific locations of the muscle. Therefore, if the placement on the volunteer subject were slightly off, that could have caused some of the contributions of noise. Due to these manipulations, the EMG sensor data have the least amount of reliability among the other sensors, as there is a lot of room for user error. However, regardless of these potential causes for the noise, there was still significant amounts of data collected. The average of these sensor readings after they were cleaned were charted, these values can be seen in Figure 5.

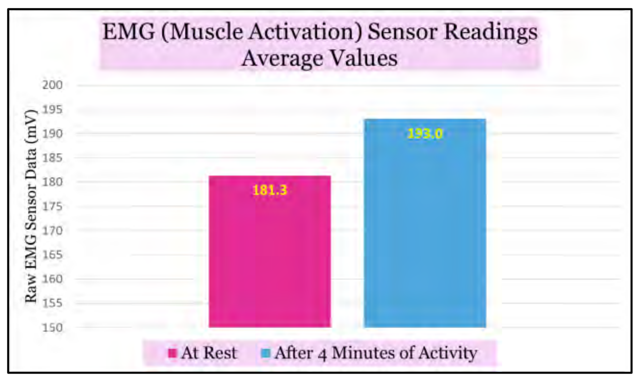

Figure 5. EMG Muscle Sensor Results

As during increased stress, we found that the average rate of muscle activation was higher after the four minutes than the baseline values found during the "At Rest" trial (as shown in Figure 5). This could potentially be attributed to residual tension or stress built up in the muscle from the activity period.

The final sensor readings that were explored were from the GSR Sensor and is shown in Figure 6. Our tests showed a decrease in skin resistance, which corresponds to an increase in perspiration. The act of perspiration causes the skin's pores and surface to be filled with sweat (which contains conductive salts), and thus the GSR sensor will find the skin to be more conductive (or less resistive). The data we collected is consistent with what one would expect to see during exercise. There was a decrease in average sensor values from the "At Rest" collection to the "After 2 Minutes of Activity" collection, and another decrease from the "After 2 Minutes of Activity" collection to the "After 4 Minutes of Activity" collection. Thus, showing that the low-cost GSR sensor selected for the biosensor proof-of-concept device could have the potential to track levels of skin resistance to a degree that could be used for a more advanced prototype design.

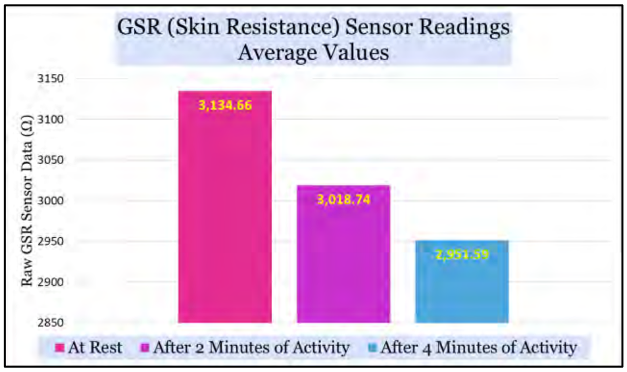

Figure 6. GSR Skin Resistance/Perspiration Sensor Results

4. Conclusion

Though the data gathered in this experiment from the EMG, PPG, and GSR sensors were measuring physical stress on the body, physical stress is known to have very common sympathetic responses as psychological stress[37]. Though the two types may be able to be differentiated, both have the potential to cause a reaction in the same systems— the heart might pound, muscles might strain, and sweat droplets may appear.

Moreover, due to the results from this device showing that these sensors show predictable changes in these systems during times there is known physical stress on the users body, future studies should be conducted to test the devices ability to also capture situations of psychological or emotional stress. In addition, further research should be conducted regarding the calibration and consistent set-up of the EMG electrodes if the MyoWare Sensor and MyoWare Cable Shield is selected for future studies.

5. Future Work

There have been a lot of great advances in BSN systems, body sensor networks, which are systems that incorporate multiple wearable or implantable biosensors working together to perform a common task [36]. The next steps with this proof-of-concept prototype device would be to make each sensor component wireless and network enabled. It could then be a real-time stress monitoring system that could potentially differentiate from the different types of stress, as has already been shown to be possible[25].

There could then be functionalities added such as an associated phone application or Bluetooth notification system enabled so that the wearer of the biosensor stress-detection device could be notified promptly of how their external environment is effecting their body, ideally before they would even be conscious of such effects. This would in turn lead to a more body-conscious and self-aware user, as well as a help the user to manage some of the harmful effects of stress on the body. The wearer could feel more empowered to take a greater influence over their mental health – all from the knowledge the low-cost, accessible system could provide.

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6. References

[1] El-Bakry, H.M., & Mastorakis, N.E. (2009). Personal identification through biometric technology.

[2] Yaribeygi, H., Panahi, Y., Sahraei, H., Johnston, T. P., & Sahebkar, A. (2017). The impact of stress on body function: A review. *EXCLI journal*, *16*, 1057–1072. https://doi.org/10.17179/excli2017-480

[3] Heineman W.R., Jensen W.B. Leland C. Clark Jr. (1918–2005) Biosens. Bioelectron. 2006;21:1403–1404. doi: 10.1016/j.bios.2005.12.005.

[4] Bhalla, N., Jolly, P., Formisano, N., & Estrela, P. (2016). Introduction to biosensors. Essays in biochemistry, 60(1), 1–8. https://doi.org/10.1042/EBC20150001

[5] Frank, D.L., Khorshid, L., Kiffer, J., Moravec, C.S., & McKee, M.G. (2010). Biofeedback in medicine: who, when, why and how? Mental health in family medicine, 7 2, 85-91 .

[6] Critchley, H. D. (2002). Review: Electrodermal Responses: What Happens in the Brain. *The Neuroscientist*, *8*(2), 132–142. doi: 10.1177/107385840200800209

[7] Bach, D. R., Friston, K. J., & Dolan, R. J. (2010). Analytic measures for quantification of arousal from spontaneous skin conductance fluctuations. International

journal of psychophysiology : official journal of the International Organization of Psychophysiology, 76(1), 52–55. https://doi.org/10.1016/j.ijpsycho.2010.01.011

[8] Boucsein, W. (2012). Electrodermal Activity. Boston, MA: Springer US.

[9] American Psychological Association. (n.d.). Stress effects on the body. Retrieved from https://www.apa.org/helpcenter/stress-body

[10] Healthy Lifestyle: Stress Management. (2020, March 21). Retrieved from http://www.mayoclinic.org/healthy-lifestyle/stress-management/basics/stress-relief/hlv-20049495

[11] Henriksen, A., Mikalsen, M. H., Woldaregay, A. Z., Muzny, M., Hartvigsen, G., Hopstock, L. A., & Grimsgaard, S. (2018). Using Fitness Trackers and Smartwatches to Measure Physical Activity in Research: Analysis of Consumer Wrist-Worn Wearables. *Journal of Medical Internet Research*, *20*(3). doi: 10.2196/jmir.9157

[12] Yin, Z., Zhou, Y., & Li, Y. (2020). Seismic Exploration Wireless Sensor System Based on Wi-Fi and LTE. Sensors, 20(4), 1018. doi:10.3390/s20041018

[13] J. Wijsman, B. Grundlehner, H. Liu, J. Penders and H. Hermens, "Wearable Physiological Sensors Reflect Mental Stress State in Office-Like Situations," 2013 Humaine Association Conference on Affective Computing and Intelligent Interaction, Geneva, 2013, pp. 600-605.

[14] TheTouchPoint Solution™. (n.d.). TouchPoints for Calm. Retrieved from https://thetouchpointsolution.com/products/touchpoints-for-calm

[15] Muse™. (n.d.). Muse2. Retrieved from https://choosemuse.com/muse-2

[16] BodiMetrics Performance Monitor. (n.d.). Retrieved from https://www.allheart.com/bodimetrics-performance-monitor/p/bmbm88/?s=one%20size&c=&gclid=CjwKCAjwg6b0BRBMEiwANd1_SDSax2Wau0zAm455hg3PEjsthy9Iypo_GDOkSmJALc2DtSPgMFkCnBoCIPQQAvD_BwE

[17] E4 wristband. (n.d.). Retrieved from https://store.empatica.com/products/e4-wristband?variant=17719039950953

[18] Train for relief. (n.d.). Retrieved from https://getlief.com/order

[19] Poh, M.-Z., Swenson, N. C., & Picard, R. W. (2010). A Wearable Sensor for Unobtrusive, Long-Term Assessment of Electrodermal Activity. IEEE Transactions on Biomedical Engineering, 57(5), 1243–1252. doi: 10.1109/tbme.2009.2038487

[20] Heineman W.R., Jensen W.B. Leland C. Clark Jr. (1918–2005) Biosens. Bioelectron. 2006;21:1403–1404. doi: 10.1016/j.bios.2005.12.005.

[21] Setz, C., Arnrich, B., Schumm, J., Marca, R. L., Troster, G., & Ehlert, U. (2010). Discriminating Stress From Cognitive Load Using a Wearable EDA Device. IEEE Transactions on Information Technology in Biomedicine, 14(2), 410–417. doi: 10.1109/titb.2009.2036164

[22] Andrasik, F., & Rime, C. (2007). Biofeedback. Pain Management, 1010–1020. doi: 10.1016/b978-0-7216-0334-6.50125-4

[23] Ahmed, M. U., Begum, S., Funk, P., Xiong, N., & Scheele, B. V. (2011). A multi-module case-based biofeedback system for stress treatment. Artificial Intelligence in Medicine, 51(2), 107–115. doi: 10.1016/j.artmed.2010.09.003

[24] A. Hasanbasic, M. Spahic, D. Bosnjic, H. H. adzic, V. Mesic and O. Jahic, "Recognition of stress levels among students with wearable sensors," 2019 18th International Symposium INFOTEH-JAHORINA (INFOTEH), East Sarajevo, Bosnia and Herzegovina, 2019, pp. 1-4.

[25] Sharpley, C.F., Gordon, J.E. Differences Between ECG and Pulse When Measuring Heart Rate and Reactivity Under Two Physical and Two Psychological Stressors. J Behav Med 22, 285–298 (1999). https://doi.org/10.1023/A:1018724608328

[26] Allen, J. (2007). Photoplethysmography and its application in clinical physiological measurement. Physiological Measurement, 28(3). doi: 10.1088/0967-3334/28/3/r01

[27] Lee, H., Song, C., Hong, Y. S., Kim, M. S., Cho, H. R., Kang, T., … Kim, D.-H. (2017). Wearable/disposable sweat-based glucose monitoring device with multistage transdermal drug delivery module. Science Advances, 3(3). doi: 10.1126/sciadv.1601314

[28] Majumder, S., Mondal, T., & Deen, M. (2017). Wearable Sensors for Remote Health Monitoring. Sensors, 17(12), 130. doi: 10.3390/s17010130

[29] Salai, M., Vassányi, I., & Kósa, I. (2016). Stress Detection Using Low Cost Heart Rate Sensors. Journal of Healthcare Engineering, 2016, 1–13. doi: 10.1155/2016/5136705

[30] Jonckheere, J. D., Ibarissene, I., Flocteil, M., & Logier, R. (2014). A smartphone based cardiac coherence biofeedback system. 2014 36th Annual International Conference of the IEEE Engineering in Medicine and Biology Society. doi: 10.1109/embc.2014.6944695

[31] Xiong, J. (2010). Design of Health Relaxation System Based on Biofeedback from Finger Sensors. 2010 *International Conference on Innovative Computing and Communication and 2010 Asia-Pacific Conference on Information Technology and Ocean Engineering*. doi: 10.1109/cicc-itoe.2010.40

[32] Koga, K., Nakayama, I., & Kobayashi, J. (2013). Portable biological signal measurement system for biofeedback and experiment for functional assessment. *2013 13th International Conference on Control, Automation and Systems (ICCAS 2013)*. doi: 10.1109/iccas.2013.6704003

[33] Wu, W., Zhang, H., Pirbhulal, S., Mukhopadhyay, S. C., & Zhang, Y.-T. (2015). Assessment of Biofeedback Training for Emotion Management Through Wearable Textile Physiological Monitoring System. *IEEE Sensors Journal*, *15*(12), 7087–7095. doi: 10.1109/jsen.2015.2470638

[34] J. Taelman, T. Adriaensen, C. van der Horst, T. Linz and A. Spaepen, "Textile Integrated Contactless EMG Sensing for Stress Analysis," *2007 29th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, Lyon, 2007, pp. 3966-3969.

[35] K. Chen, W. Fink, J. Roveda, R. D. Lane, J. Allen and J. Vanuk, "Wearable sensor based stress management using integrated respiratory and ECG waveforms," 2015 IEEE 12th International Conference on Wearable and Implantable Body Sensor Networks (BSN), Cambridge, MA, 2015, pp. 1-6.

[36] F. Lebepe, G. Niezen, G. P. Hancke and T. D. Ramotsoela, "Wearable stress monitoring system using multiple sensors," 2016 IEEE 14th International Conference on Industrial Informatics (INDIN), Poitiers, 2016, pp. 895-898.

[37] Harvard Health Publishing. (n.d.). Understanding the stress response. Retrieved from https://www.health.harvard.edu/staying-healthy/understanding-the-stress-response