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GALVANIC SKIN RESPONSE DURING PAIN PRESSURE THRESHOLD TESTS

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A b s t r a c t

This study aims to see the correlation between skin resistance and pain during pain pressure threshold tests. A Galvanic Skin Resistance sensor is used to measure the patient's skin resistance. Two electrodes are placed on two adjacent fingers. A blunt tipped tool is pressed into the patients median nerve, located between the index finger and thumb. This area is known to usually be tender and with little force can inflict noticeable pain. This ensures no long term physical damage to the patients tissue. Sixty tests were made in total on the test subject, the author. On each test there are two noticeable dips in skin resistance. One, when the tool first contacts the patients skin, and another when pain is actually felt. Graphs depicting the direct correlation between force and skin resistance are made to visualize at what force the patient had the lowest skin resistance.

Introduction

Humans have a few involuntary actions or reflexes which can be triggered by physical pain. These includes a phenomenon called galvanic skin response. Galvanic skin response – GSR is a reaction to a physical stimulus MARKIEWICZ (2022), which increases stress. An example can be an increasing force with a blunt

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object on certain nerve endings, which will cause the parasympathetic nervous system to open the patients sweat glands GERŠAK (2020). This is turn lowers the resistance of the patients skin due to increased secretion of sweat VILLAREJO (2012). A resistance metering device can log this data and plot it to visually assess this variable during pain pressure threshold tests CHON (2020). It is also known that this electro dermal activity can be used to register strong emotions. Not only physical pain influences the change of skin resistance SAID (2019). A vast array of emotions can cause noticeable changes in this value. A polygraph or lie detector heavily relies on this sensor in order to determine the probability of a subject telling lies COOK (2019). The design of a GSR metering device uses operational amplifiers to condition the signal LESTARI (2020). Different people have different reactions to physical stimulation and nominal skin resistance levels KIM et al. (2019). That is why it is important to create a baseline before conducting any test involving this sensor. The usual delay between an input and reaction of human while monitoring their electro dermal activity ranges from 0.2 s to 1.0 s.

Pain pressure threshold tests are a way to quantify a patient's pain level. The main device used for these tests is called an algometer. Currently algometers have a digital read out of a pressure sensor attached to the tip of the device. The tip itself is slightly convex and has a specified area, usually around 10 mm^2 in order to provide repeatable data on numerous parts of the human body. The way a test is conducted is by gradually increasing the applied pressure to a patients area of interest to a point when the patient verbally or visually informs the operator to stop the test. When the test is stopped, the last registered value is assumed to be the point which is the patients pain pressure threshold. Due to varying levels of patients pain tolerances and their incentive to not exactly say when they feel pain for their own personal gain, these tests are rather subjective KAMIŃSKA (2020). They do not monitor any type of body reactions to this physical stimulus and completely rely on the patient's own feedback.

A way to overcome this subjectiveness is to monitor a patient's electro dermal activity to provide a more precise and unbiased way of pinpointing their pain levels. While it is currently impossible to accurately determine this value due to EDA LI (2022) and parasympathetic nervous system being not fully understood SCHUBERT (2009) it is a way to add quantifiable data alongside the patient's own feedback during these tests. This is a new layer of data that can be used to confirm if the point in which the patient feels pain is valid or not.

The goal of this experiment is to quantify the moment at which a patient feels pain. The end result should be a force value that coincides with the sudden drop is skin resistance. This study contains sixty test results from the same patient, the author. Thirty tests were done on one hand and thirty on the other hand. No damage is done to the patients hand since a pain pressure threshold test only aims to get a value when a patient starts feeling pain. Only areas that are tender or produce pain with low force are selected, such as the median nerve in this test. The force applied is comparable to a deep massage and while it may and is supposed to cause discomfort, it shouldn't cause long term tissue damage.

Materials and methods

Materials

This section can be divided into two distinct categories each representing a specific component of the test bed. A block diagram is show in Figure 1 and the actual test bed is shown in Figure 2. One part consists of a ESP32 Dev Module with the GSR sensor board and its probes and the other part is the ESP32S3 HMI display. The test bed itself was constructed with off the shelf components and programed in way to easily view data in a spreadsheet editor. It uses several Arduino libraries, such as HX711 for the force sensor, LVGL for the graphic interface on the HMI display, ESPNow for wireless communication and a SD card library for saving data into a CSV format. Using this program the raw data can be formatted into data sets and plots can be created to visualize the results.

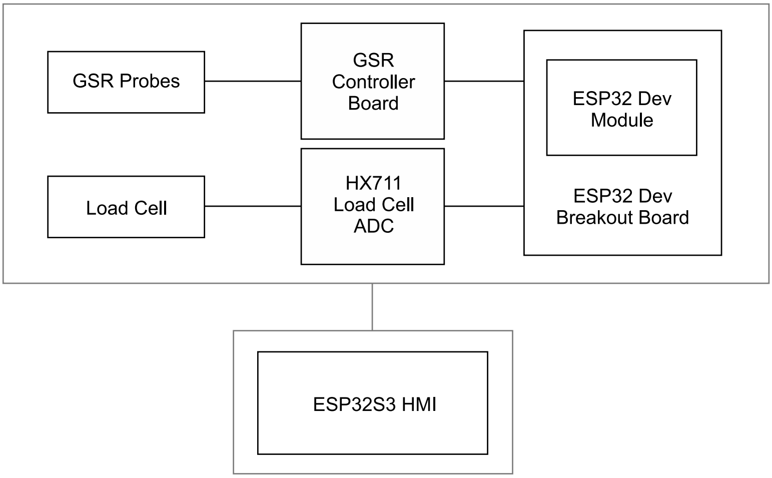

Fig. 1. Tests bed block diagram

Fig. 2. Actual Test bed

Starting off with the electro dermal activity sensor, it is a galvanic skin resistance sensor created by Grove, Seeed Technology Co., Ltd. China Figure 3. The version used in this test bed is the latest version 1.2. It features two electrodes shown in Figure 3, which are attached to two adjacent fingers on one hand. The electrodes consist of two small finger sleeves which ensure a tight fit between the skin of the patient and the nickel plated electrode. This is a one size fits all sleeve, however in testing a person with small fingers may cause the electrodes to shift with slight movements of their fingers and create artefacts in the signal. Within the Grove sensor a small circuit board with three operational amplifiers condition the voltage from the electrodes. The GSR sensor uses one of the analog to digital pins of the ESP32 to transfer data. The output data of the sensor is a number between 0 and 1023 which represents a voltage between 0 and 3.3 V which is the voltage of which the ESP 32 runs on. On the software side this value is converted into the value of electrical resistance expressed in Ohms. Also in order to minimize fluctuations in readings, the sensor data gets a simple average filter from the last 3 readings. The readings are sampled at around 5 ms each, then a simple average calculation is made and the final result is sent to the HMI display. The sensitivity of the device was adjusted following the manufacturers procedure to minimize the serial output fluctuations. As in a surface mount potentiometer was adjusted until the sensors readings were stable. Once adjusted, it was set at that setting for the duration of the tests, even if due to slightly different conditions, outliers in theory would benefit from readjustment. This is for consistency reasons and further along proved that the sensor even in unfavorable conditions can carry out its given task. These unfavorable conditions are for example different room temperatures, different initial stress levels, different body temperatures. These tests were done over the span of a couple days and slightly different initial conditions could occur.

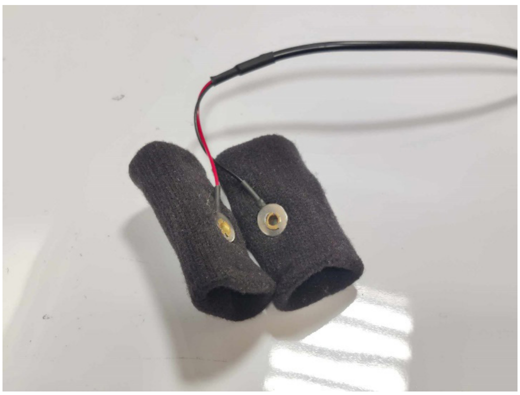

Fig. 3. GSR finger probes

The second sensor is a F2812-50N WIKA Alexander Wiegand SE & Co. KG, Germany loadcell used as a force sensor. It is a 50 N button type loadcell calibrated for linearity from the factory shown in Figure 4. Its connected to a HX711 ADC module. The module itself is connected to the ESP32 Dev Module breakout board just as the GSR sensor module. As for the code it uses a HX711 library, it's also calibrated in the code and has a simple average filter. This ensures that data is easily readable in Newtons and removes most of the fluctuations. Its frequency in data acquisition is also limited to about 100 ms. As previously mentioned with the GSR sensor this is limited by a few factors, however for this application it is deemed to be adequate. The senor itself has two threaded rods, one attached to its housing and another attached to its probe. A FDM 3D printed handle is screwed on to its immovable housing rod end. A M5 extension nut is screwed onto the probe end and a hex key screw is attached to this extension. This allows to mount a small FDM 3D printed cap to the hex head for a larger convex probe tip. A standard for pain pressure threshold tests is a 10 mm^2 surface area of the probe tip.

Fig. 4. Load cell force tool

The ESP32 Dev Module is mounted to a breakout board to more easily connect it to different modules, in this case the previously mentioned GSR module and a HX711 24 bit Analog to Digital Converter. It is enclosed in a FDM 3D printed case shown in Figure 5, with the breakout boards power connectors exposed. It can run off of a 3.5 V – 9 V power supply, in practice a 5 V USB cable is used. ESPNow is used as a wireless communication protocol. It sends two integers in one data packet. One integer for the loadcell values and the other one for GSR readings.

The last component of this test bed is the CrowPanel 5.0”-HMI ESP32 Display shown in Figure 6 from Elecrow. It acts as a visual indicator of the readings from the pain pressure threshold test and also serves as a data logger to a SD card. The visual part of the screen is simple. It features one screen. On it there

Fig. 5. ESP32 Dev Module Case

is a plot area featuring three different plot lines and two interactive buttons below it. The three plot lines correspond to the force sensor on the blunt tipped tool, the GSR sensor reading and a generated force guide line. For better visibility, the force and GSR values are appropriately scaled for both of them to fit on the screen. The displayed values do not directly correspond to the raw values sent by the other ESP32 dev module. However the raw values are saved to the SD card. A blue line that acts as a guide line is generated by increasing the target value each time the screen refreshes. This increasing target value ensures that the operator of the blunt tipped tool has the ability to steadily increase the force inflicted on the region of interest.

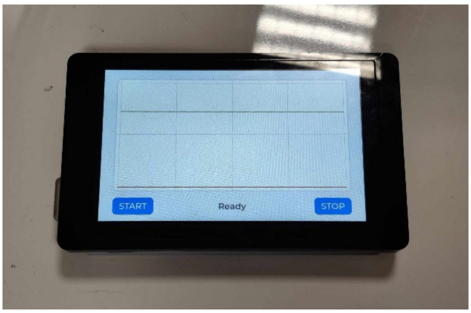

Fig. 6. HMI display

The two buttons are for starting a new test and saving the current test. Each test generates a new name for its CSV file and while the test is running it appends new values to this file. This button also hides the GSR sensor value plot line. This is done due to certain discrepancies during testing possibly caused by anticipation of the GSR values to suddenly dip. During initial trials the added stress of looking at these values interfered with the pain pressure threshold procedure. During testing only the current force value and the target force value is displayed. The stop button stops this appending process and closes the file. These CSV files include three data types. A time value directly corresponding to the time of data acquisition by the ESP32 HMI display and the raw force values and GSR values. It also shows the previously hidden during testing GSR plot line.

Methods

The testing procedure goes as follows. The HMI display and ESP32 Dev Module is powered on and their communication is established. On the HMI display three lines are plotted. A green line represents the force value of the blunt tipped tool and a red line represents the GSR sensor readings. Communication can be checked by pressing the tip of the force tool and checking the HMI display for its response. The test can start when the GSR sensor values become steady. When this happens the start button can be pressed, and data is recorded to the SD card. A blue line steadily moves up as this is the target force value. The blunt tipped tool is pressed into the median nerve located in Figure 7 and its force adjusted to hover around the target force plot line. The test is stopped when a force value of 3kg is reached. The stop button is pressed after 10 seconds to observe if there are any fluctuations in skin resistance values when pressure is rapidly removed. The saved CSV file can now be read on a computer.

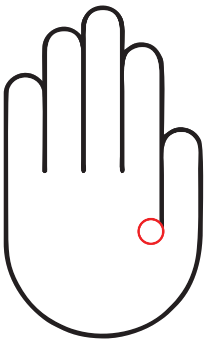

Fig. 7. Applied pressure location

Results and discussion

The following results are selected from thirty tests. A few of them are handpicked in order to show what a typical test looks like and how it may be used to identify when a patient feels pain. The results are shown as a plot comparing skin resistance values to applied force. By removing the aspect of elapsed time, it is easier to visualize their relationship and draw conclusions rather than analyzing the scaled down version of two plots, one showing applied force values and the other skin resistance over time. The key is to identify any significant drops in resistance corresponding to specific force ranges.

This Figure 8 shows the view from the HMI display. As mentioned before two plots are generated in relation to time passed. The blue line is skin resistance and the orange line is applied force. Subtle fluctuations in skin resistance are visible, however in this scale they are difficult to see. Even if they are easy to distinguish, another obstacle is to correspond this dip in skin resistance to a specific force range. For this reason the following plots will compare skin resistance directly to applied force.

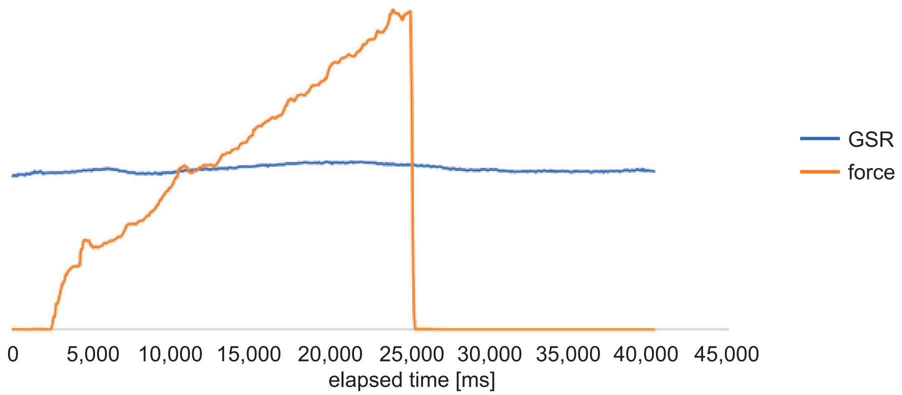

Fig. 8. Time based from data set 1

This Figure 9 and the following plots greatly improve visibility when it comes to pinpointing in what range of applied force the skin resistance is the lowest. In this specific plot the lowest skin resistance is within the 15-18 N range. This is right after a peak in skin resistance at around 14 N. After this dip skin resistance rises as stress levels return to normal even though the applied force rises. The other dip happens after a peak at around 40 N.

Another chart in Figure 10 shows that the lowest dip in skin resistance, that happens after a peak is at around 22 N, while the peak happens at around 20 N. This means that when the force reached around 20 N, the patients stress levels peaked and the involuntary secretion of sweat lowered the skin resistance to as low as 900 Ohms. Another dip also happens at around 38 N.

This data set in Figure 11 is a bit different when compared to the previous ones. The first dip after a steady stream of skin resistance values, happens at around 13 N. Another Dip happens after a peak at around 30 N. These values are offset earlier at around 10 N, when compared to the previous plots.

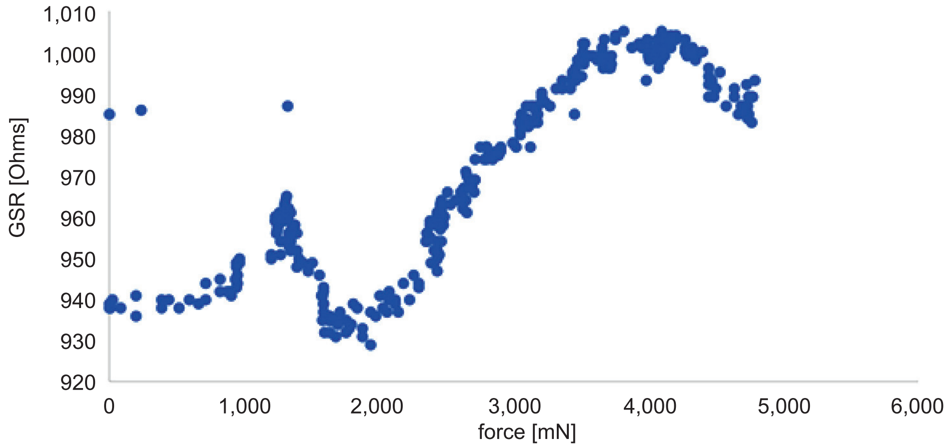

Fig. 9. Comparison from data set 1

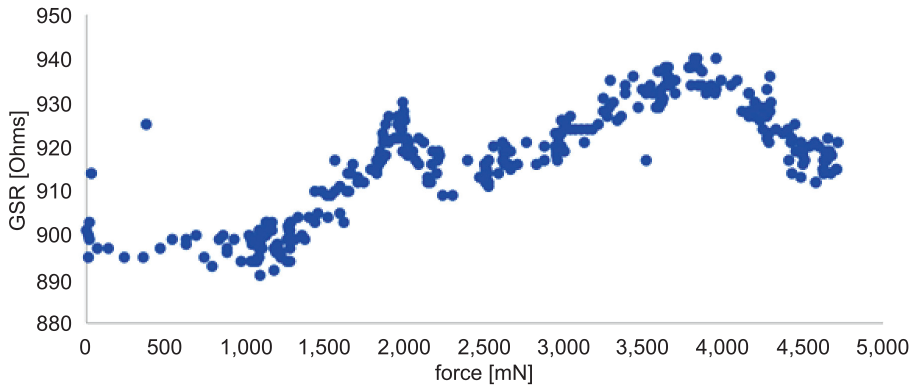

Fig. 10. Comparison from data set 2

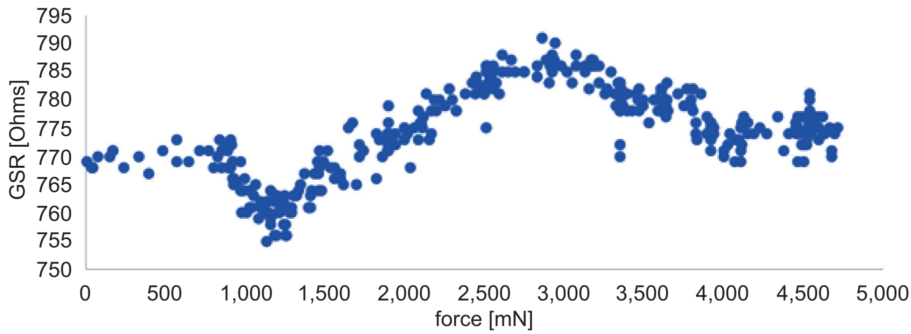

Fig. 11. Comparison from data set 3

This plot in Figure 12 also is offset by a bit, the first dip is barely noticeable, at around 11 N, and the second dip happens after a peak at around 35 N. This shows that even if the received data shows very little deviation can be still pinpointed on a simple scatter plot.

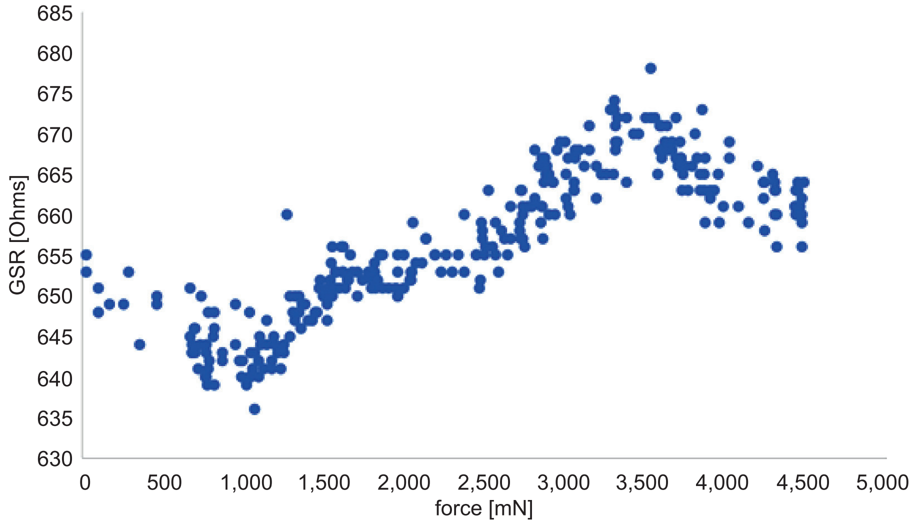

Fig. 12. Comparison from data set 4

This data set from Figure 13 shows the first dip at around 12 N and the second dip, after a peak at around 38 N. Once again as in all the previous plots there are two observable dips. The first one happens at a lower force value and the other one after a continued rising force.

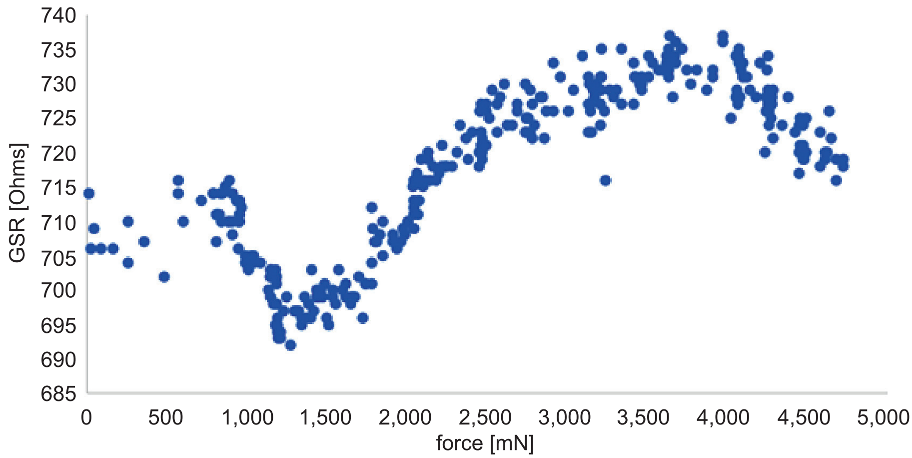

Fig. 13. Comparison from data set 5

This data set in Figure 14 is slightly different than the previous plots, however two skin resistance dips are also visible in more or less the same applied force values. The first dip is at around 11 N and the second one at around 30 N.

This concludes the proper results. Further test results show what happens when initial conditions are not met or improper testing procedure occurs.

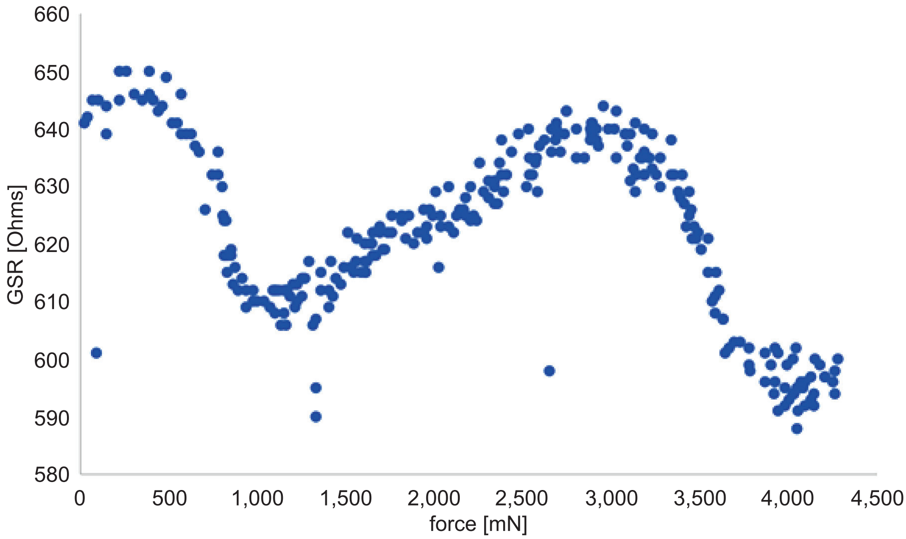

Fig. 14. Comparison from data set 6

The plots above Figure 15 and 16 are from the same data sets. As it can be seen even though a steadily rising applied force is sustained throughout the test, the skin resistance readings stay more or less the same. On the lower scatter plot there is no readable data. In this test the median nerve was not targeted accurately and just the patients skin was pressed against the tip and the surface below the hand. Even when a high force was applied, due to little nerve endings on the area around the median nerve, no reaction to pain was registered.

In this test it is evident that the tip of the tool slipped during testing. The upper plot Figure 17 showing the force applied over time, indicates that just after the test started, the median nerve was not targeted correctly and the tip slipped. This can be also seen on the lower plot Figure 18, where skin resistance steadily increases as the initial highest stress was caused by the slip, and no significant discomfort was caused during the rest of the test.

This test in Figure 19 shows what happens when the finger probes from the GSR sensor are not properly attached to the patients hand. During the test a sudden rise in skin resistance occurred due to shifting of the GSR probes.

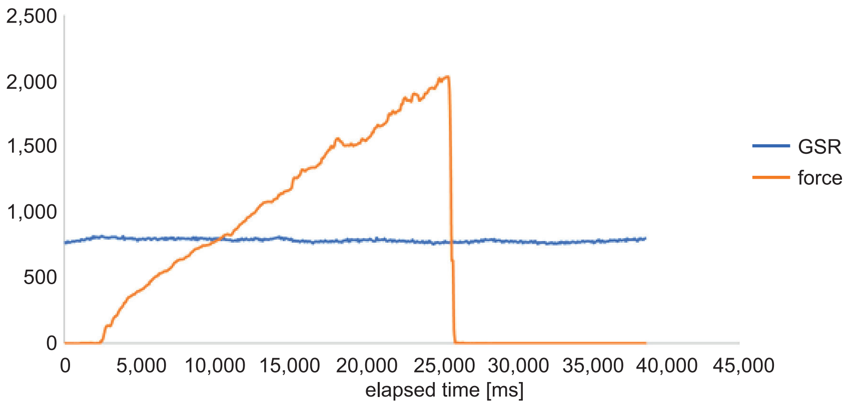

Fig. 15. Time based from data set 7

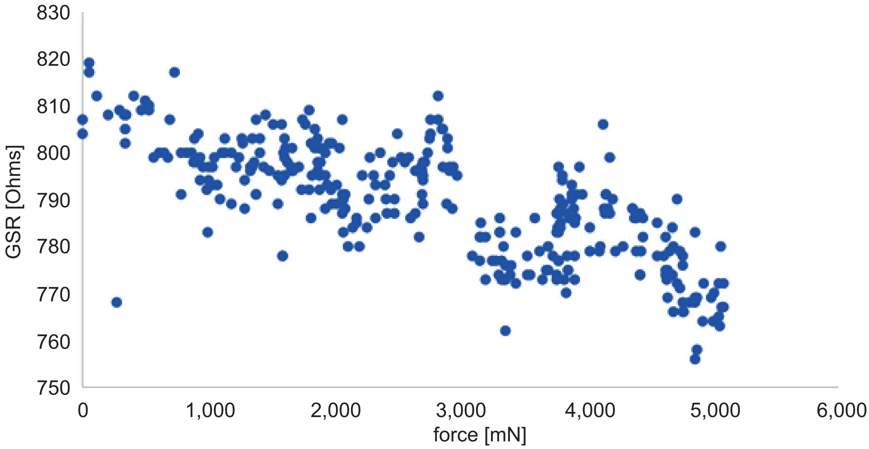

Fig. 16. Comparison from data set 7

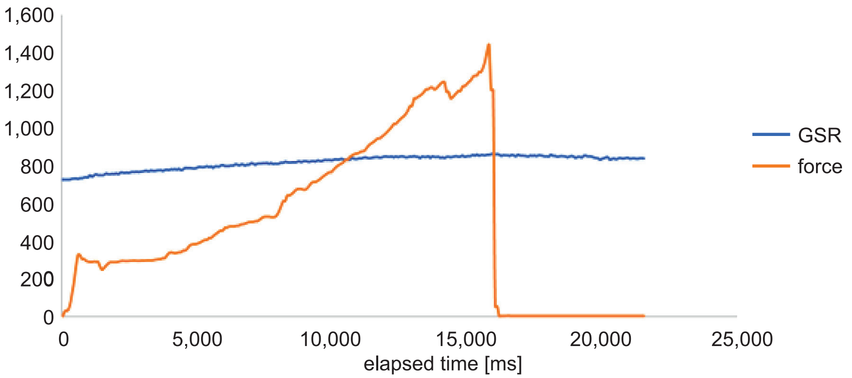

Fig. 17. Time based from data set 8

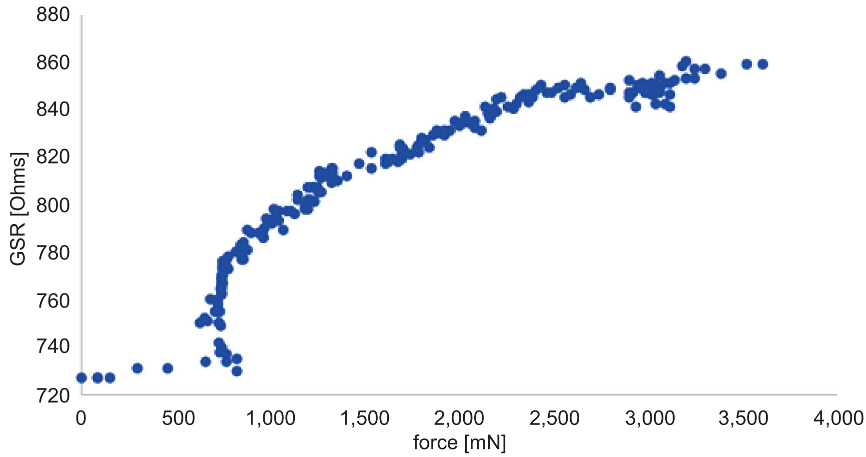

Fig. 18. Comparison from data set 8

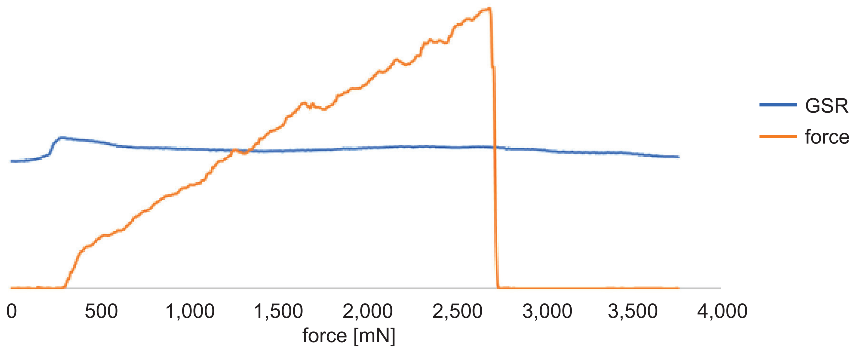

Fig. 19. Time based from data set 9

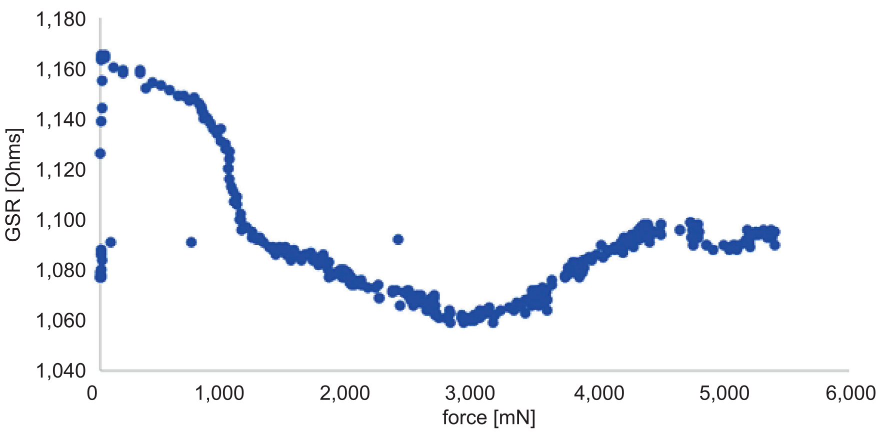

Fig. 20. Comparison from data set 9

This happened at the same time the probe was pushed against the patients hand, which could have caused this movement. When this happened the direct comparison between applied force values and skin resistance in Figure 20 is no longer readable. The sudden spike caused the second plot to shift its values and they are no longer corresponding to their correct X and Y values.

Discussion

The selected plots showing a proper result all have at least two things in common. Two dips in skin resistance at two different force values. The first dip usually happens at around 11-15 N. This could indicate that since this is an involuntary reaction, the true applied force value at which pain is felt happens a bit earlier. This is difficult to pinpoint, however due to the repeatable results it can be safe to assume that pain is felt before or at 10 N. The second dip usually happened after a peak of 3-40 N. This could indicate that there is a second, higher stress level that is achieved at higher force values. This is outside the scope of this experiment, since only the first reaction to pain is brought into account.

Regarded the improper results, they most commonly occurred due to a few reasons. The main reason is not directly contacting the median nerve with the tool tip. This nerve is quite small, and the margin of error is low. Another occurrence is that the tip of the tool slips midway through the test or right after starting the test. This caused sudden fluctuations in applied force readings, which in turn provided inconclusive data when it comes to pinpointing the exact range when pain is felt. Another factor is the GSR sensor probes, slight movements of the patients fingers sometimes caused spikes in skin resistance readings. This means that operator error is the key factor when it comes to improper readings.

The initial conditions did not have much impact on the testing procedure and results. The tests were done over the course of a couple of days in the same room with the same temperature. Even when these conditions stayed relatively the same, the initial skin resistance values changed. This can be narrowed down to the patients different initial stress levels, and or nominal skin resistance levels. Hydration and stress are known contributing factors to initial skin resistance values, however even without a strict water intake of the patient, data could be extracted and conclusions can be made.

Conclusions

– Two distinct drops in skin resistance are found in the GSR to Force plots.

– The first drop corresponds to the patients pain pressure tolerance.

– Since the drop in skin resistance is a reaction to increased stress levels, it is safe to assume that the actual pain force value happens before the first dip.

– The patients force value at which pain is felt is before or at 11 N.

– A second higher force at around 30-40 N indicates that even with a steadily rising force, a higher level of stress can be achieved and its reaction can be observed.

– Operator error is the key factor when it comes to improper readings.

This paper evaluated how a humans galvanic skin response can help determine when a patient feels pain. The goal was to determine when a patient feels pain. This was somewhat achieved by analyzing plots comparing skin resistance values to applied force values. The reason it's not entirely accurate is caused by the fact that the secretion of sweat caused is caused by a reaction to stress. The time between observing the decrease in resistance and actually feeling pain is not accurate enough to precisely pinpoint at what force value a patient actually feels pain. What can be known is that the value at which this happens is before the dip is skin resistance. That means that if the lowest skin resistance was achieved at 12 N, the force which caused this reaction happened before 12 N. This can provide a quantifiable value which can be compared to other patients or even between the left and right hand of the patient in order to assess the patient's condition.

This device as it is could be used as a medical assessment tool in several areas. As mentioned before the patient could have pain in one of their hands and this tool could compare both areas. The area with a lower pain tolerance is indicative that there is a problem with this side of the patient's body. Furthermore, several tests over the span of the patients therapy could indicate the progress of therapy and whether the proper treatment is chosen.

These tests may be further expanded by testing a greater amount of test subjects. Also the amount of force may be applied in a more accurate manner by introducing a electronically controlled actuator with a load cell probe that could be used in a feedback loop to regulate the applied force. This could greatly improve the consistency and repeatably of conducted tests. A device like this combining the technology of a regular algometer and the sensing capabilities of the modules used in this experiment could quite possibly improve the quality of life of patients.

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