Analysis of the Relationship between Electrodermal Activity and Heart Rate with Pain in Individuals with a Shoulder Pathology

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Abstract: Currently, pain analysis in a clinical environment is not common and is at fault for being subjective and always dependent on a personal response. Therefore, it is imperative to use physiological signals to quantify pain and make diagnosis more objective. This article aims to study the relationship between pain, through its analog scale, with the electrodermal and cardiac signals of individuals characterized by having a shoulder pathology that gives rise to recurrent pain. This study was carried out on 21 patients from Hospital Curry Cabral, who were part of the Occupational Therapy department's care in the area of Physical Medicine and Rehabilitation, and 18 individuals without any pathology, thus serving as a control group. All participants followed an experimental protocol consisting in the measurement of electrodermal and cardiac signals and pain level when performing two different movements. The results suggest that there is indeed a relationship between the two measured signals and pain. The greater the pain experienced by the individual, the greater the amplitude of the electrodermic signal and heart rate appears to be.

1 INTRODUCTION

Over the years, due to various technological advances, a new ability to obtain and process physiological signals has emerged. It is thanks to these technological advances that it is possible to deepen the knowledge on numerous pathologies and consequently improve the clinical diagnosis. Several innovations in technology are responsible for this improvement, from new physiological signal acquisition devices to new signal processing tools. However, there are still many pathologies that lack an easy and objective clinical diagnosis, as is the case of orthopedic diseases. This is a consequence of the diagnosis not being made by collecting and analyzing physiological signals. Many of these pathologies can originate in the way people live their daily lives, from the physical activity performed to their job. Although physical exercise has great benefits for both physical and mental health (Warburton et al., 2006), excessive or incorrectly performed physical activity can lead to orthopedic injuries (Gabbett, 2016). Jobs that require repetitive movements or high physical strain, such as jobs in construction or factories using the assembly line system, can lead to such pathologies, particularly in the shoulder (Mitchell et al., 2005), having already been a concern performing a rotation of workers in different positions on the assembly lines, so as to vary the type of movements made by them. It is the difficulty in diagnosing these pathologies that motivates the development of new techniques and technologies in order to make the diagnosis easier and more objective. These conditions often make a healthy and pain-free life impossible, so it is imperative that solutions be found for their correct diagnosis. However, the quantification of pain is subjective, since it uses analog scales and depends on each individual's perception of pain. This leads to subjective and inaccurate diagnoses (Kandel et al., 2000). Thus, the correct quantification of pain, in a non-subjective way and based on physiological signs, becomes essential. The Nervous System of an

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individual after experiencing pain, namely the Sympathetic Nervous System, produces a change in sweat excretion and heart rate, and these changes are translated into the electrodermal signal (EDA) (Ströfer et al., 2015) and the electrocardiogram (ECG) (Shaffer et al., 2014), respectively.

Thus, this study aims to collect these signals and correlate them with an analog pain scale, always aiming to make the quantification of pain more objective.

2 MATERIALS AND METHODS

The study was approved by the Portuguese Ethics Committee of Hospital Curry Cabral, in Portugal. Each participating subject was informed about the procedures and the objectives of the study, prior data collection, and signed a consent form with this information.

All data was collected, during 3 months, from a cohort of patients, with a shoulder pathology that gives rise to recurrent pain, attending the occupational therapy department's care in the area of Physical Medicine and Rehabilitation in Hospital Curry Cabral.

This study was carried out on 21 patients and 18 individuals without any pathology, among the student population of FCT-NOVA, and thus serving as a control group.

Characterization of the Sample

The sample is easily divided in two different groups: the patients group (P) and the healthy individuals group (H). The P group is composed by 21 patients, 15 female and 6 male, with an average age of 64 ± 12 years old. The H group consists in 18 healthy individuals, 11 male and 7 female, with an average age of 24 ± 3 years old. Although the two groups have different ages, as the data was processed separately for the two samples, the authors consider that the results remain valid.

2.1 Instruments

For data collection, the Biosignalsplux equipment, was used. From the available sensors, an EDA sensor was used to measure the electrodermal signal, an ACC (accelerometer) sensor to assist in timing and an ECG sensor for heart rate estimation. The ECG sensor has 3 channels and the EDA sensor has 2 where the electrodes are attached after their fixation on the individual. It is through these set channels / electrodes that EDA and ECG are collected. Solid gel disposable ECG electrodes with an easy contact with the skin were used. The recording device collects the physiological signals simultaneously, with a 16-bit resolution and sampling frequencies of 1000 Hz. All data is transmitted, via Bluetooth, from Biosignalsplux to the computer for processing (Plux, 2019).

All signals were processed using program Matlab R2017a.

2.2 Procedure

The team composed by biomedical engineers and some occupational therapists at Hospital Curry Cabral identified the movements as well as all the steps to be performed during the protocol. The experimental protocol always follows 3 sequential steps: explanation of the experimental protocol; electrode placement; acquisition of EDA, ACC and ECG signals; signal analysis.

1) Explanation of the Experimental Protocol

Initially it is always explained to the participants the purpose of the study and how data collection will be performed in order to obtain the informed consent. If the participant agrees to their collaboration in the study, the informed consent is signed. After this first step it is needed to fill out a short form designed to characterize the individual (age, profession, medication, etc.).

2) Electrode Placement

After filling in the form, follows the placement of the electrodes. The two EDA sensor electrodes are placed on the front of the hand, as shown in Figure 1. The hand where the electrodes are placed will always be the opposite of the arm that will make the movements. Thus, the required movements do not interfere with the measured signal, since the hand in which it is recorded, was as static as possible. The 3 ECG electrodes are also placed, two on the chest and one on the right foot next to the talus bone, as shown in Figure 2. In the case of healthy individuals, the arm that performs the movements always corresponds to the dominant hand.

3) Acquisition of EDA, ACC and ECG Signals

A video with the exact duration of the collection was created to assist in data acquisition. The video shows which movements to perform and the moments in which participants have to execute them. In the first phase the participants are sitting at rest. After 1 minute and 30 seconds they perform the first movement - shoulder flexion with elbow extension - followed by a further period of 1 minute and 30 seconds at rest. After this second rest period the

participants perform the second movement - internal rotation of the shoulder with elbow flexion. Both movements are represented in Figure 3.

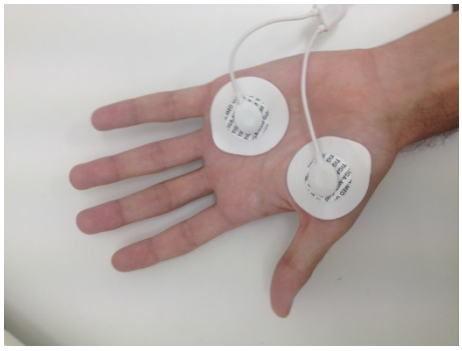

Figure 1 Example of placing the electrodes corresponding to the EDA signal on the front side of a participant's hand moments before a collection.

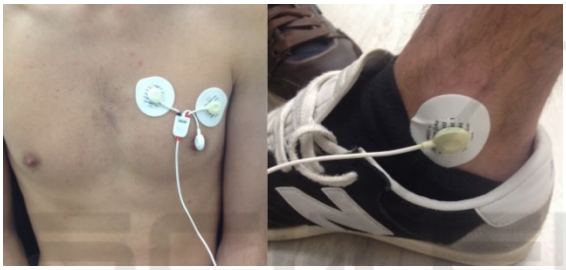

Figure 2: Example of placement of the electrodes corresponding to the ECG signal on a participant's chest and talus moments before a collection.

Figure 3: Representation of the two movements made during data collection. On the left - shoulder flexion with elbow extension, and on the right - internal shoulder rotation with elbow flexion.

This process continues until there are 6 shoulder flexions with elbow extension and 5 shoulder internal rotations with elbow flexion, ending with a rest period. After each movement, the participant is asked the intensity of the pain they felt, using the Numerical Pain Rating Scale (Hjermstad et al., 2011, and the answer is added to the participant's form. This scale is a subjective measure and consists of eleven equal parts, numbered successively from 0 to 10 (Hjermstad et al., 2011). The patient is asked to make the equivalence between the degree of pain and the numerical score, with 0 corresponding to "no pain at all" and 10 to "worst imaginable pain".

Participants are also asked to exert a little more effort on the last three movements to cause a slight increase in pain. The timing of all the movements is set by the ACC sensor. An up-down sensor rotation indicates the beginning of a movement and a down-up rotation indicates the end of a movement.

4) Signal Analysis

After collecting all data, the processing phase begins. The first step is to smooth out the EDA signal as it has some noise. For this purpose a sliding average filter is applied. The window of this filter is 5 points and the method used was the Savitzky-Golay (Savitzky and Golay, 1964). The instants of the beginning and ending of each movement are also drawn in the same graph, using the values from the ACC sensor. In Figure 4 is shown the result of this processing.

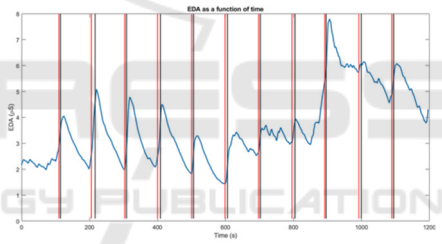

Figure 4: Electrodermic signal (μS) of patient 03 and moments of the beginning, marked in red, and the end, marked in black, of the movements after the use of the sliding average filter.

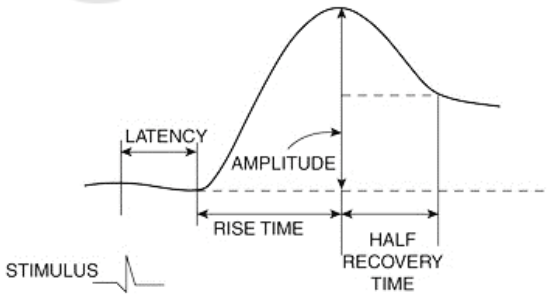

Figure 5: Representation of the features extracted from EDA signal (Dawson et al., 2016).

The skin conductance responses were analyzed using the following features: amplitude, rise time and half recovery time. These features were extracted through the determination of the maximum value of

the stimulus response and the baseline level (Figure 5). The maximum value of the stimulus response is always the highest amplitude value measured after the movement and the baseline is the upward facing concavity point always found on the left of the highest amplitude point. The amplitude is the difference between the maximum response value and the baseline value. Rise time is calculated as the difference between the time indices of the maximum amplitude points and the baseline. The half recovery time requires more calculation as it is necessary to calculate the amplitude point at half height. This point will have an amplitude equal to the difference between the maximum value and half the amplitude of the stimulus response and is always on the right of the stimulus response. The half-recovery time is then calculated by making the difference in time indices between this point now found and the point of maximum amplitude.

In order to carry out a study of the average EDA responses of all sample, it was necessary to normalize the collected signals. For each individual, the amplitude of each response was divided by the highest amplitude recorded. Thus obtaining for all individuals amplitudes between 0 and 1.

For processing the ECG signal R-waves were detected to create a graph showing heart rate as a function of time, since heart rate is the inverse of the time interval between consecutive R waves. Figure 6 shows a portion of an electrocardiogram collected during the performance of the protocol. These were detected with the help of the Matlab *findpeaks* function, using 20 points as the minimum peak distance and 5 times the average of the prominence of all peaks as minimum peak height options. Following the creation of this graph and due to misidentification of R waves, signal smoothing is performed, thus eliminating false R waves. (see Figure 7). This smoothing was performed with the *medfilt1* function, which applies a 10th order median filter to the signal.

Following the creation of the latter graph, and similar to what was done with the electrodermal signal, the maximum value of the stimulus response and the baseline values are extracted so that the amplitude can be calculated. Since the start and end times of all movements are the same on the HR graph and EDA graph, it is easy to identify the heart response to movement and do that to pain.

Regarding HR study, one is interested in the difference between the peak value of HR response to movement / pain and the basal value found immediately before the response to movement (DIF (HR)). Similarly to the EDA approach, also this difference is normalized by the highest difference HR obtain for each subject.

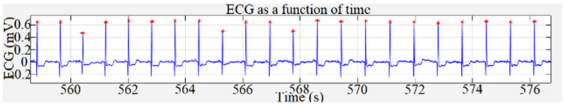

Figure 6: Electrocardiogram of patient 02 recorded during data collection. R Waves are highlighted.

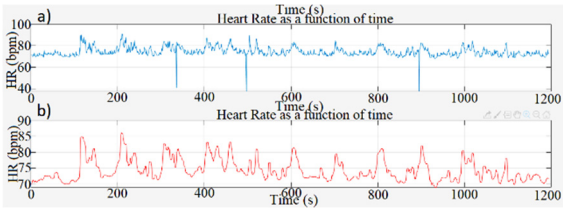

Figure 7: Heart rate as functions of time, a) original and b) smoothed. Graphs relative to patient 02.

3 RESULTS AND DISCUSSION

The results obtained in this study are divided into two parts. The first one is about the healthy individuals group and the second one about the patients group.

3.1 Healthy Group

The first important idea to mention is that even without causing pain, movements performed during the experimental protocol cause an increase in the EDA signal, as expected. Figure 8 shows a column chart for one healthy participant, showing the amplitude of the EDA along the sequence of movements.

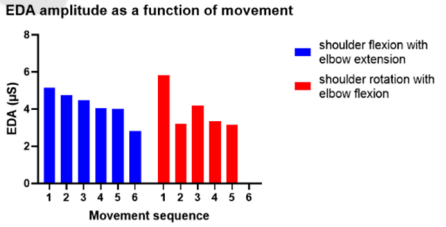

Figure 8: Electrodermic signal amplitude of healthy individual 01 along the sequence of movements.

It is apparent that the amplitude of the electrodermic signal is higher in the first movements and then gradually decreases. This response behavior is thought to be related to some subjective factors. Namely, the stress / surprise caused by starting a new task This behavior is observed in about one third of healthy participants, with the rest showing similar

amplitude throughout the protocol or, in rare cases, sporadic increases. The latter may be due to factors outside the experimental protocol (room temperature and involuntary auditory stimuli, for example).

Due to the gradual decrease mentioned above and considering that the protocol starts with shoulder flexion and elbow extension, the average response amplitude is expected to be greater in this movement (see Figure 9). Taking that into consideration, it is also relevant to note that the amplitude of the stimulus response is not movement dependent, in the heathy group.

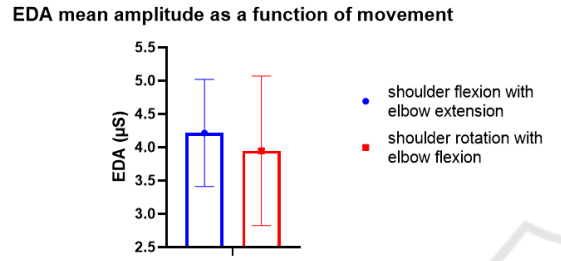

Figure 9: Mean amplitude of the electrodermic signal of healthy patient 01 for both movements.

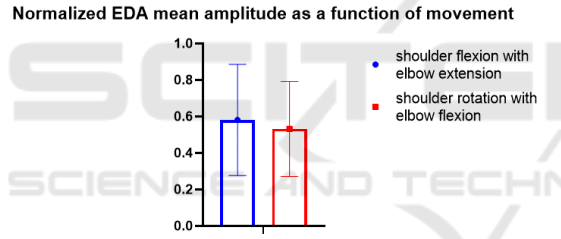

Figure 10: Normalized mean amplitude of the electrodermic signal of all healthy participants for the two movements performed.

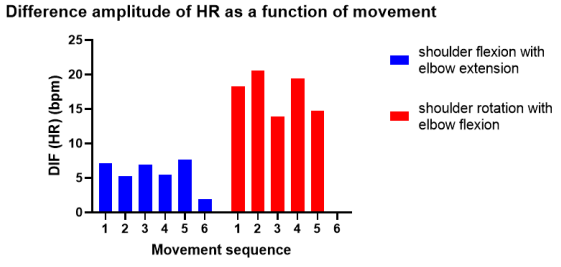

Figure 11: Heart rate amplitude of healthy individual 17 for both movements.

This idea is also corroborated by the graph shown in Figure 10, where the mean and standard deviation of the normalized signals for each movement were shown.

Similar to the EDA signal, heart rate also increases after a movement. Figure 11 depicts the heart rate column graph along the sequence of movements in one subject with typical behavior.

In Figure 11 it is evident that there is a clear difference in HR amplitude relative to both movements. It is an effect manifested in more than half of participants without pathology. The others have an average difference in HR amplitude similar between the two movements. Thus, when all these differences for all individuals without pathology are normalized, the shoulder rotation movement with elbow flexion presents an arithmetic average superior to the shoulder flexion movement with elbow extension (see Figure 12). A possible explanation for this effect could be that the shoulder rotation movement with elbow flexion requires more physical effort.

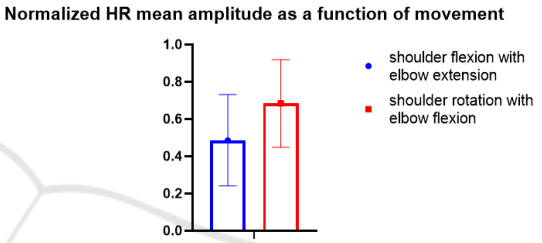

Figure 12: Normalized HR mean amplitude of all healthy participants for both movements performed.

3.2 Patients Group

For the patient group, an analysis similar to the previously presented one, the non-pathological group, was performed. In addition, the patient group included information regarding the pain score.

Figure 13 shows the amplitude of the EDA along the sequence of movements, for patient 20.

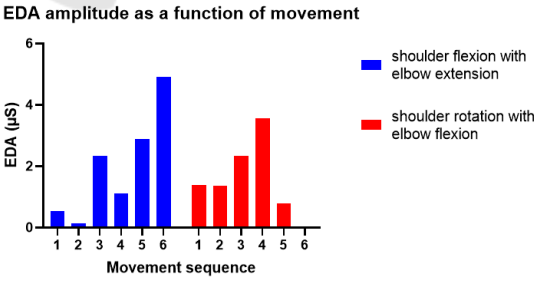

Figure 13: Amplitude of the electrodermic signal of patient 20 along the sequence of movements.

In Figure 13 it is clear that the amplitude of the EDA does not remain constant and does not gradually increase or decrease along the sequence of movements, as it was observed in the healthy group. This effect is present in 90% of participants with

pathology. This difference from what happens to individuals without pathology could be explained by the pain felt when performing the movements.

In order to understand how pain influences the electrodermal signal, graphs of the amplitude of the EDA as a function of pain score were created for all individuals with pathology (see Figure 14 for) patient 20.

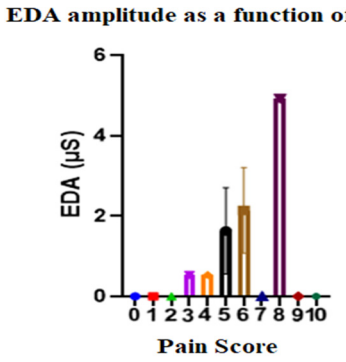

Figure 14: Electrodermic signal amplitude of patient 20 as a function of pain score.

In Figure 14 it is evidenced that higher pain levels correspond to higher EDA amplitudes. However, we observed that in the case of patient 12, among others, this effect is not so easily visible (see Figure 15). Since the difference between consecutive pain levels is very difficult to distinguish, it was decided to divide the pain scale into three classes: minimal pain (pain levels 0, 1, 2 and 3), average pain (pain levels 4, 5 and 6) and maximum pain (pain levels 7, 8, 9 and 10). Thus it becomes even more evident that when the pain experienced is greater, the amplitude of the EDA signal is also greater. Figure 16 show the graphs of the amplitude of the EDA as a function of pain score for patient 12, after the pain scale division.

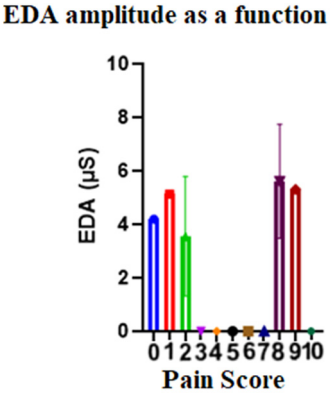

Figure 15: Electrodermic signal amplitude of patient 12 as a function of pain score.

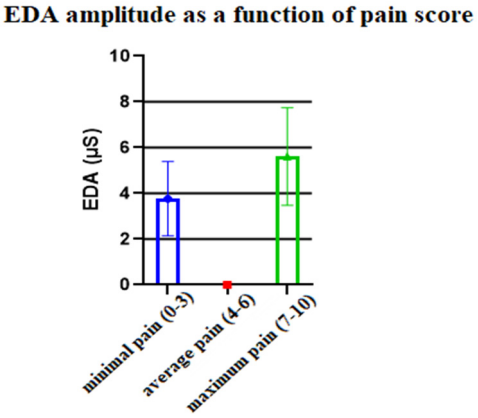

Figure 16: Electrodermal signal amplitude of patient 12 as a function of grouped pain score.

Taking into account all individuals with pathology, a graph of the mean normalized amplitudes was created as a function of the grouped pain scores (see Figure 17).

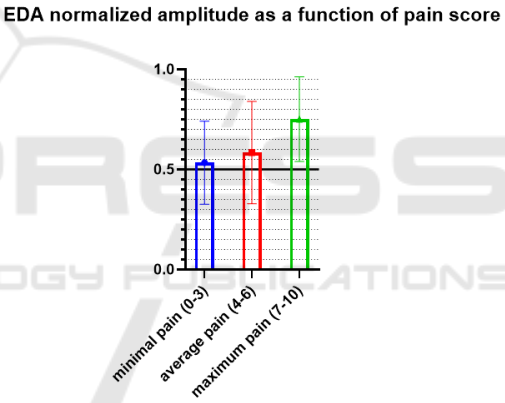

Figure 17: Normalized mean amplitude of the electrodermic signal of all participants with pathology as a function of the grouped pain score.

Concerning all participants with pathology, in only two the amplitude of the EDA as a function of the grouped pain score shown a different behavior than the one observed in Figure 17. It should be notes that although the graph in figure 17 contains information from these two patients and also from patients who did not experience pain levels in the full spectrum of the scale, the "greater pain - greater amplitude" ratio of EDA is still clearly visible.

Regarding heart rate, an analysis very similar to that of the electrodermal signal was performed. Figure 18 shows the HR data along the sequence of movements for patient 19. It is apparent that the differentiation of HR data from the two movements is no longer evident as it was for individuals without

pathology. This is true for all patients and can also be explained by the existence of pain when performing the movements. This means that the effect of pain overlaps the effect of physical effort observed in the control group.

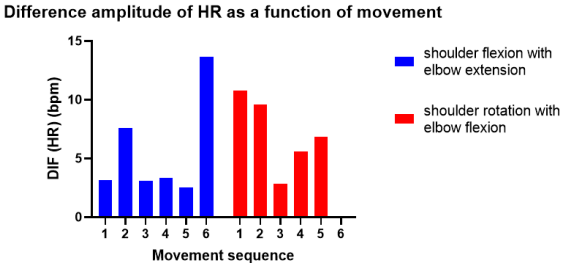

Figure 18: Heart rate amplitude of patient 19 for both movements.

Similarly to what was performed for the EDA, the pain scale was divided into three parts and the HR amplitude graphs were created as a function of the grouped pain scores (for example, see Figure 19 related to patient 16.

As with the electrodermal signal, heart rate also increases as pain experienced by patients increases, however, this relationship is not as linear as that which appears to be present in the EDA signal. This is shown in Figure 20, which has the pain-related HR information for all individuals with pathology. Again, it was necessary to normalize all amplitudes for all subjects individually, as before, and to do the arithmetic mean and standard deviation for each group of pain levels. As could be observed, the maximum pain also corresponds to maximum heart rate, but the amplitude corresponding to the minimum pain is slightly greater than that corresponding to the average pain.

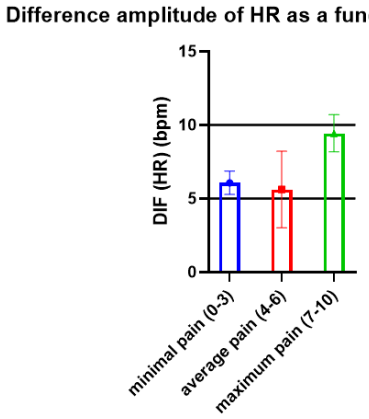

Figure 19: Heart rate amplitude of patient 16 as a function of grouped pain score.

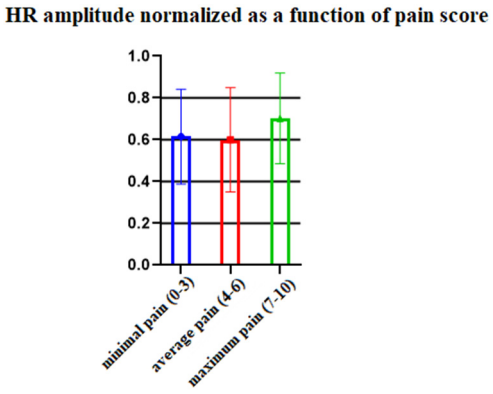

Figure 20: Normalized mean amplitude of the heart rate of all participants with pathology as a function of the grouped pain score.

4 CONCLUSIONS

Through the analysis of the obtained data it can be concluded that there is a pain-EDA as well as a pain-HR relationship. For both EDA and HR, the greater the pain experienced by the individual, the greater the amplitude of the respective signal. This is a clearly observable relationship when comparing only low and high pain scores.

In the future, it will be important to have a larger and more homogeneous sample, in terms of age as well as in pain scores. It would be, also, interesting to conduct a similar study in individuals with pathologies located elsewhere, for example in the leg, or even of a different pathologies, for example, neurological disorders.

Thus, it is important to continue the study of the relationship between pain and physiological signs in order to achieve stronger conclusions. Once stablished a clear relationship between pain scores and physiological signals, the clinicians will be able to access an objective tool of diagnosis and intervention.

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