Evaluation of Using an Inexpensive Wearable Device – Movesense – to Measure Electromyography.

Utvärdering av att använda en billig bärbar enhet - Movesense - för att mäta elektromyografi.

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Abstract

Work-related musculoskeletal disorders are very common in Europe and induce high costs for companies and society. In order to prevent disorders, risk assessments are needed. Today, risk assessments are usually carried out by using observational risk assessment methods, e.g. QEC, RULA, HARM, OCRA. These methods are easy to learn and to use, but all have a rather low reliability; different observers obtain different risk estimates. To improve the reliability of risk assessments, there is a need to develop objective methods that are easy to use, so that they may be used by occupational health practitioners. Technical methods have previously been too complex and too expensive for practitioners to use, but now the electronics devices are getting smaller and cheaper. There are also techniques to transfer signals via Bluetooth with low energy consumption, i.e. to save battery.

Occupational health researchers have, via studies including these complex measurement methods, shown associations of e.g. muscle activity (measured with electromyography (EMG)) and generation of musculoskeletal disorders. The aim of this project is to use a smartphone as a base and use the Movesense Showcase app, a low-cost method, that together with an external device (e.g. a ECG measuring Movesense sensor) measure and show statistics of EMG for different efforts. The results showed that this method could be a suitable and functional method that could replace standard EMG methods because of being cheaper and easier.

If an easy-to-use EMG smartphone app is developed, the usage of Movesense for EMG measurements will likely be attractive to use not only among occupational health actors, but also in sports and rehab applications.

Keywords

Movesense, Electromyography, EMG, Musculoskeletal disorder, MSD, Risk Assessment

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I have several people to thank for this thesis. People who have always been by my side supporting me since this project began. First, I must thank for the help received from my supervisors Mikael Forsman and Antonio Martínez Millana, both great experts in their field. On the other hand, I must thank all the people who are part of my family. To my parents and sister for supporting me unconditionally, even though they did not understand at all what I was doing and sometimes I was upset or in a bad mood. To Maria for helping me in all my ups and downs and understanding me in every moment that the project was going through. Also, many thanks to all the people who are part of my life today, the people who little by little have touched parts of my way and have built me up to what I am today.

And last but not least, thank you to me, for not giving up and keeping fighting until the end. Because “the best prize that life has to offer is the chance to work hard at work worth doing” [1].

List of Abbreviations

API	Application Programming Interface
APK	Android Application Package
ARV	Average Rectified Value
BLE	Bluetooth Low Energy
CSV	Comma-Separated Values
DFU	Device Firmware Update
ECG	Electrocardiogram
EMG	Electromyogram
sEMG	Surface Electromyography
ED	Extensor Digitorum
HR	Heart Rate
JSON	JavaScript Object Notation
LED	Light-Emitting Diode
MVC	Maximal Voluntary Contraction
MVE	Maximal Voluntary Electrical Activity
MNF	Mean Frequency
MDF	Median Frequency
MU	Motor Unit
MUAP	Motor Unit Action Potential
MSD	Musculoskeletal disorders
nEMG	Normalized Signal
PSD	Power Spectral Density
RMS	Root-Mean-Square Value
SDK	Software Development Kit
SD	Standard Deviation
SEK	Swedish krona
tw	Time Window
USB	Universal Serial Bus

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1. Introduction

Musculoskeletal disorders are one of the most important health problems found in the workplace in both industrialized and developing countries, causing work absenteeism in Europe and reducing the profitability of companies. These problems affect people's quality of life and are a major expense in several countries around the world, such as the Nordic countries [2].

The European Agency for Safety and Health at Work already proposes a plan for the reduction of Musculoskeletal disorders (MSDs) as they affect 30% of the population; among young people between 15 and 24 years affecting 25%, and 35% among those over 55 [3], [4].

Surface electromyography (sEMG) is one of the tools used as part of a risk assessment for work-related MSDs. For normalization sEMG *hand grip* method (see [5]) is usually used as Maximal Voluntary Contraction (MVC) as for example in [6]. However, an alternative MVC is *resisted wrist extension* found at [7] (see Fig. 15), that should be more reliable.

One disadvantage of sEMG is that they are expensive and difficult to use for occupations. Commercial EMGs need some software and technical knowledge and could be confusing for practitioners. Also, EMGs can reach costs as hundreds of euros (or thousands of Swedish kronas (SEKs)) and greater [8], [9].

1.1 Objective

There is a relationship between EMG force and amplitude, and its results are important for ergonomic evaluation. Although EMG has been of great help to practitioners and other health professionals, today, devices for performing electromyography are expensive and difficult to use. On the other hand, commercial EMGs cost hundreds of euros (or thousands of SEKs) on average, and can reach values of more than ten thousand euros (one hundred thousand SEKs) [8], [9]. On the other hand, technical background knowledge is needed to know how to use these machines. However, Movesense, the device used in this study costs about 40 euros (approximately, 400 SEKs) [10] which is much cheaper than commercial devices and with a simpler and more intuitive use.

The **first aim** of this study was to evaluate *Movesense's performance* when it is used for measuring EMG signals and knowing the feasibility in the field of ergonomics by using a smartphone as a base and using the Movesense Showcase app, that together with a an external device (ECG measuring Movesense sensor [10]) measure and show statistics of EMG for different efforts. This is done to see if this could be a suitable method for practitioners to use, as it is simpler and cheaper than those known previously. **Secondary objectives** are to prove, as in [7], that *resisted wrist extension* method is more useful than *hand grip* method for wrist disorders, and if the sensor is capable to discriminate the efforts done with different loads, also how the efforts are analysed statistically.

1.2 Background

a. Surface Electromyogram

Electromyography (EMG) is the recording of electrical activity (electrical potential changes) produced by muscles on the surface of the skin or with needle electrodes (inserted into the skin) [11], [12]. First EMG cited, surface EMG, is preferred in ergonomics because it is a non-invasive procedure. This method was used in all the projects the thesis was based on, as can be seen in [6], [7], [13].

The electromyography that will be described in this thesis is the one related to the skeletal muscle. Approximately 40% of the body is skeletal muscle. Skeletal muscle contracts by nerve stimulation, and it is also formed by several muscle fibers with varied size, that is, all fibers (except 2%) are innervated. These muscle fibres are long cells that extend along the bone in most cases and their action produces a high energy consumption [14], [15].

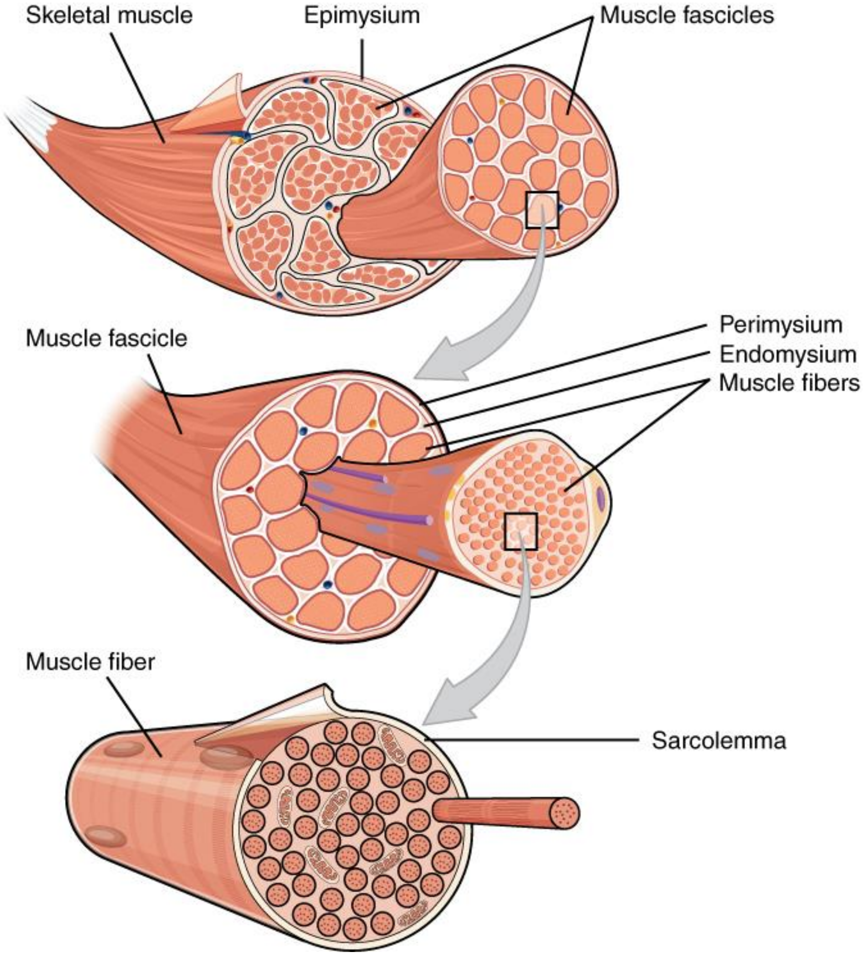


Fig. 1. Muscle structure from skeletal muscle level to cellular level [16].

The levels of skeletal muscle range from the macroscopic zone to the cellular level, where we find the muscle as such (set of fibers), the bundle of fibers, the musculoskeletal fiber (cell) that is wrapped by the sarcolemma (Fig. 1) and at its ends fuses with the tendon fibers and finally, the myofibrils, these are formed by actin and myosin filaments (large polymerized protein molecules responsible for muscle contraction) [14], [15].

When nerve impulses reach the fiber, these impulses are transformed into intracellular action potentials. The appearance of these potentials produces a potential in the extracellular environment called the action potential of a fibre. The sum of the action potentials of all the muscle fibres belonging to the same motor unit gives rise to the motor unit action potential (MUAP). The electromyographic signal obtained is the result of the temporal sum of the MUAPs of the motor units recruited. This EMG signal is obtained from the detection of the potentials through the electrodes. These potentials are varying depending on the MUAPs recruited during the activation [17]. The EMG signal can be used to detect pathologies such as Neuropathies or Myopathies [14].

There are some methods to normalize EMG, the most popular is to normalize the data to the maximum voluntary contraction (MVC) as shown in [7], but there is also an alternative where it relates all measurements to the electrical activity at MVC [7], [18]. This is called maximal voluntary electrical activation (MVE), and muscular activity during work is expressed in %MVE. It should be pointed out that, given a certain position of the electrodes, different MVEs (and MVE values) can be obtained in various lengths and muscle positions [7], [18]–[20].

The most popular method for measuring MVC is the *hand grip* method, but there is another way called *Resisted Wrist Extension* that has shown that greater MVC were achieved. This alternative method was born from searching for a better method with higher values since some work activities reached higher values than MVC obtained by *hand grip* method [7]. For this reason, risk assessment methods have been developed for to be more reliable for each muscle and each work activity [20], [21].

On the other hand, when measuring the signal, different sources of noise can be found such as motion artifacts, contact between electrodes, network interference or electrocardiographic noise. This will be solved by processing the EMG to reduce these noise sources and also to prepare the input data for further analysis. However, most EMG signal processing algorithms assume that the EMG data are of high quality, which can lead to erroneous results or interpretations if this assumption is incorrect. It is also recognized that noise contamination of EMG signals is an unavoidable problem, i.e., that raw sEMG contains irrelevant information or produce ambiguity beyond useful information. Therefore, the raw signal cannot be used directly, and pre-processing of the data is necessary to reduce noise and improve the spectral resolution of the EMG signal [11], [14]. On the other hand, if we consider that the value of the input impedance of the amplifier is finite, then we can reduce the value of the impedance of the skin-electrode interface by treating the skin, such as cleaning with alcohol or using conductive gel, otherwise we will have an attenuation in the EMG [22], [23]. Also, for an adequate signal we must consider the location of the electrodes on the skin, the dimensions of the electrodes and the distance between them. When interpreting the signal, we must take into account that we can find failures due to

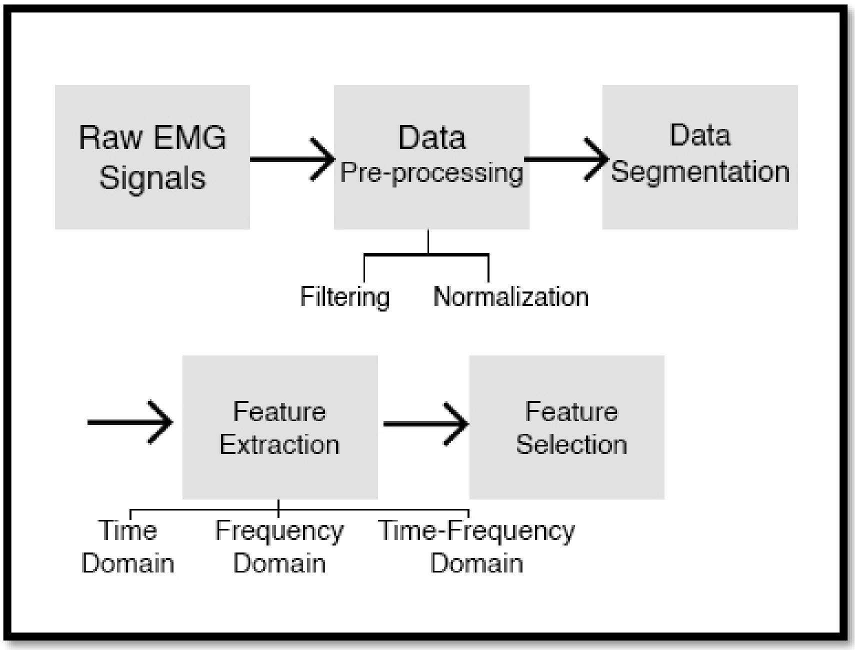


Fig. 2. Structure of EMG Signal Processing.

improper uses related to the configuration of the device. Besides, of course, problems related to data processing [9].

Once the expected signal is obtained, different measurements are made. The characteristics of the EMG have normally been divided into the time domain, the spectral frequency domain and the time scale domain (time-frequency). Amplitude, which is related to the force used by the subject and the frequency spectrum, identified with muscle fatigue, will be measured, as these are important signal characteristics for evaluation in the field of ergonomics [11], [14]. There was a study that conclude that with a time-frequency domain, they could analyse both muscle force and fatigue depending on the time and the loads [24].

The Nyquist frequency is the maximum frequency that can be present in the continuous analog signal without aliasing the discrete signal [22]. Theoretically, the highest frequency components of the EMG signal are around 400-500 Hz. It is classically assumed, according to the "Nyquist frequency" rule of thumb, that a sampling frequency of around 1 kHz is required [25]. The sampling frequency is normally on the scale of 1000 Hz, it should be at least 800 Hz [26]. Nevertheless, in this study a lower sampling frequency, 512 Hz, was used due to the limitation on the app.

Historically, myoelectric control has been mostly explored in hands-free conditions. However, as new applications emerge, the need for EMG recognition during simultaneous interactions with other objects appears. For this, while a user's hands are busy with other objects, through EMG pattern recognition, interfaces may be able to classify sets of gestures or contractions. On the other hand, there is the problem that given the newness of this field of application, few studies have been conducted with the aim of developing this type of gesture recognition interfaces for "hands-busy" conditions [11].

b. Musculoskeletal disorder (MSD)

Musculoskeletal disorders (MSD) are injuries or as their name states are disorders of the muscles, nerves, tendons, joints, cartilage and spinal discs [27], [28]. There are some conditions in which MSD are work-related, as the work environment or work performance, for example:

- Routine lifting of heavy objects/items
- Daily exposure to whole body vibration
- Repetitive forceful tasks
- Work in chronic flexion position

MSDs do not include disorders caused by slips, falls or similar incidents. The most common MSDs are:

- Sprains, strains and tears
- Back pain
- Carpal tunnel syndrome
- Hernia
- Arthritis

[27]

These injuries have been studied in different reports and the work factors have been proved as shown in [29]–[31].

Reducing stress and eliminating injuries and disorders associated with the overuse of muscles, bad posture, and repeated tasks could prevent or control this kind of injuries and illnesses. Some of these tasks with risk factors include awkward postures, repetition, material handling, force, mechanical compression, vibration, temperature extremes, glare, inadequate lighting, and duration of exposure [6], [27], [32].

The amplitude, frequency and time dimension parameters of the surface EMG can contain important information for practical ergonomic work and help reveal situations where there is a high risk of musculoskeletal disorders. Since EMG amplitude reflects force output, individual muscle participation in work tasks can be studied rather than absolute force, and therefore an ergonomic design of workplaces and tools used in the workplace can be found and evaluated. Despite this, the practitioner may have sufficient measurements with or estimates of external force, or even rely on subjective assessment or qualitative studies of perceived strain, pain or discomfort when performing tasks or using such tools [18].

Nowadays, it is demonstrated by a large number of tests that physical conditions alone cannot explain the development of musculoskeletal pain in a modern work environment. As an example, several ergonomic improvements have been made to the working environment in recent years and attempts have been made to eliminate as much as possible major physical strain such as lifting and pushing heavy loads. However, the incidence of musculoskeletal disorders (MSDs) has remained high and continues to be a major health problem for several countries around the world. MSDs are common not only in jobs that are physically demanding but also in light physical work, such as entering data into a computer or using a small part of a worker's physical capacity [2], [3], [18].

Also, MSDs are associated with worker absenteeism, lost productivity and increased health care costs, disability and workers' compensation. MSD cases are more frequent than the average non-fatal injury or illness [2], [3], [27].

c. Movesense sensor and Movesense Showcase App

Movesense device is an open development platform used in motion detection and measurement of biological parameters. Movesense is created by Suunto, Finnish sports watch expert [33]. Movesense analyse some parameters detected by the sensor and the data is transferred into the Movesense Showcase App easily. Also, Movesense has a real-time signal on the app. More about Movesense sensor and Movesense Showcase App on 2.1. Movesense sensor.

2. Materials & Methods

First of all, a Gantt chart (Appendix A) was done to organize each part of the study that was going to follow and take them on time.

As mentioned in the previous sections, electromyography in ergonomics, especially in the appearance of MSDs, provides information on muscle fatigue and force. These may depend on the amplitude of the EMG and require normalization, or changes in the frequency spectrum of the EMG. The duration of the muscle load and its rest periods are other important information found in the EMG evaluation. Indicators that reflect the change in electrical manifestations are used to evaluate these parameters. Based on the amplitude, the root-mean-square value (V_{RMS}, equation 1) and the average rectified value (V_{AVR}, equation 2) are found [9], [18], [26].

$$V_{RMS} = \sqrt{\frac{1}{T}\sum_{t=1}^{T} x(t)^2} \tag{1}$$

$$V_{ARV} = \frac{1}{T}\sum_{t=1}^{T} |x(t)| \tag{2}$$

These data depend on the sampling frequency (f_s, equation 3). Also, the mean frequency (f_{MNF}, equation 4) and the median frequency (f_{MDF}, equation 5) are found [9], [26]. These equations were found easier for coding on MathWorks ® Help Center as *meanfreq* and *medfreq* [34], [35].

$$f_s = \frac{1}{T} \tag{3}$$

$$f_{MNF} = \frac{\sum_{j=1}^{N} f_j PSD_j}{\sum_{j=1}^{N} PSD_j} \tag{4}$$

$$f_{MDF} = \frac{1}{2}\sum_{j=1}^{N} PSD_j \tag{5}$$

On the other hand, in order to normalise the EMG data, the maximal voluntary efforts are used to calculate the value of the normalised electromyogram (nEMG) which, when calculated in percentages, gives %MVE (x_n, equation 6) [7], [9], [26].

$$x_n = 100\left(\frac{x_i - x_{minimum}}{x_{maximum} - x_{minimum}}\right) \tag{6}$$

2.1 Movesense Sensor

Movesense is an open development platform used in motion detection and measurement of biological parameters. This platform is useful because of the ease of building a portable device, as well as being an economical way to do so. Movesense is created by Suunto, Finnish sports watch expert [33].

Movesense is a battery-powered device that incorporates low power sensor components with a low-energy Bluetooth enabled (BLE) microcontroller unit. The Movesense sensor is based on Nordic Semiconductor's nRF52 BLE chip equipped with a 9-axis motion sensor, a heart rate unit, additional memory and more features discussed below [36].

The basic Movesense system consists of one or more Movesense sensors and a mobile device (iOS or Android). Use consists of using Movesense device services from the mobile device. Movesense Showcase Apps are developed using the Movesense Device SDK and are updated on physical devices over-the-air via mobile applications [36].

a. Movesense Sensor

Movesense has two types of sensors: Movesense Sensor and Movesense Sensor HR+. Both sensors are the same except that the later adds a heart rate variant of the Movesense sensor, thus improving heart rate monitoring [10], [37]. They can be differentiated by a writing on the device that says HR (Fig. 3). To connect the sensor with the mobile device, there is a red LED that shows when flashing that the Sensor is on and ready to connect (Fig. 4).

Fig. 3. Front and rear of the Movesense HR+ device. In a red square it is the HR+ mark.

Fig. 4. Front and rear of the Movesense device while flashing. It is possible to see the LED light on. In addition, there is no HR+ mark on the back.

The characteristics of these sensors can be found on their website [10], [37]. The sensors available inside the Movesense sensor are:

- Accelerometer, range: ±2/±4/±8/±16g full scale, sampling frequency: 12.5/26/52/104/208Hz
- Gyroscope, range: ±125/±245/±500/±1000/±2000 dps full scale, sampling frequency: 12.5/26/52/104/208Hz

- Magnetometer, range: ±4/±8/±12/±16 gauss full scale
- Temperature, accuracy: ±0.5°C (max) from 0°C to +65°C and ±1.0°C (max) from −40°C to +125°C
- Heart rate and single channel ECG

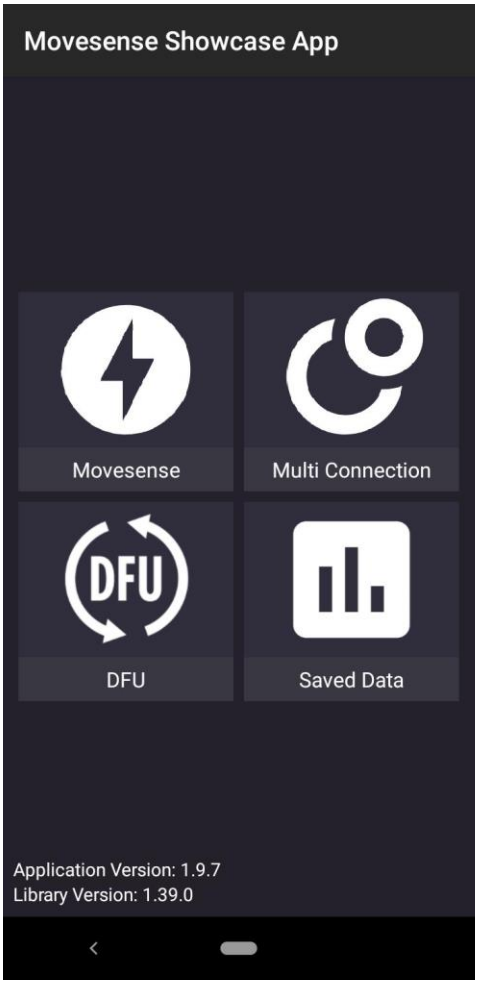
[10]

The linear acceleration sensor provides data on all three axes of motion and acceleration and is even capable of calculating position. It is measured in m/s^2. The available sampling frequencies are 12.5 Hz, 26 Hz, 52 Hz, 104 Hz, 208 Hz. In addition, different acceleration sensitivities can be set, as long as care is taken not to do so while the data is being measured to avoid strange behaviour. The ranges found are ±2 g, ±4 g, ±8 g and ±16 g at full scale. The energy consumption of the accelerator is low, as for all sensors and Movesense in general, but for efficient work with the accelerometer, this must be considered in addition to the accelerator sampling frequency. The gyro measures tilt and angular velocity in units of degrees per second (dps). It can be configured, similarly to the accelerator sampling frequencies and range. The available sampling frequencies are the same as those of the accelerometer, and the available ranges are ±125, ±245, ±500, ±1000, ±2000 dps at full scale. The magnetometer also measures the magnitude of changes in the planet's magnetic field. The available ranges are ±2, ±4, ±8 and ±16 gauss at full scale. Then, the temperature sensor has an accuracy of ±0.5 °C between measures from 0 °C to +65 °C and an accuracy of ±1 °C from -40 °C to 125°C, i.e. for extreme temperatures. Also, the Movesense sensor is water resistant up to 30 m. Besides, the Movesense Sensor HR+ can measure heart rate and a single channel ECG [10], [38].

b. Movesense Showcase App

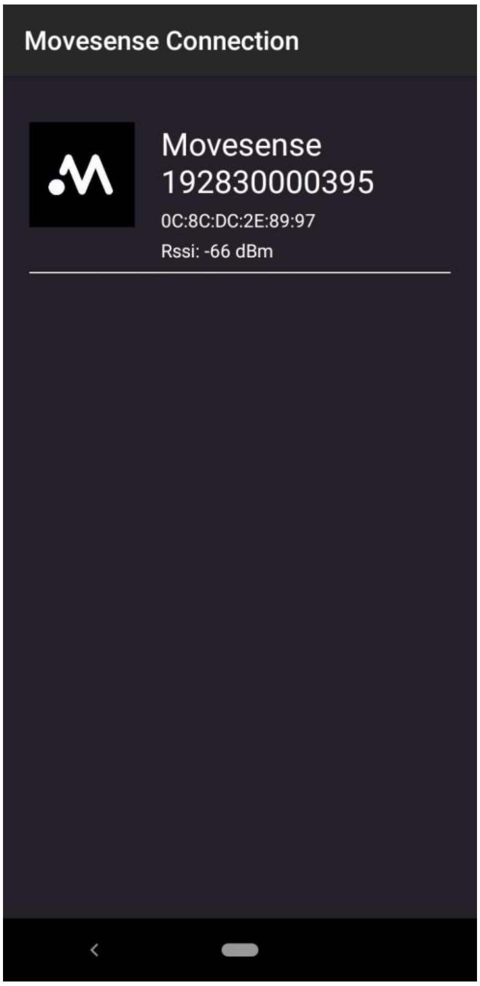
The application description is done for Android Operative System. This application provided by Suunto consists of a first panel in which the possibilities of what can be done appear. In this panel the application title appears at the top: *Movesense Showcase App*. In the lower part can be seen the application version, 1.9.7. in this case, and the library version, 1.39.0. In the centre of the panel there are four squares corresponding to *Movesense, Multi Connection, DFU and Saved Data* where their functions are described below (Fig. 5).

- Movesense: when *Movesense* is entered, a new panel is found with the title *Movesense Connection* (Fig. 6). The desired Movesense sensor can be connected here. The number below the Movesense name is the characteristic number of the desired sensor to be linked. The sensor number is located on the back of the device (Fig.3 and Fig.4).



Application Version: 1.9.7
Library Version: 1.39.0

Fig. 5. Movesense Showcase App, the first screen found.



Movesense
192830000395
0C:8C:DC:2E:89:97
Rssi: -66 dBm

Fig. 6. Movesense Connection screen, where the devices are ready to connect.

- Multi Connection: This panel titled *Multi Connection* is dedicated to the connection of more than one sensor (Fig. 7).

- DFU: This panel has the function of updating the system, both the library and the app (Fig. 8). To perform a correct update, first *Select file* folder must be selected and followed by selecting the Drive folder (or similar storage) where the update versions are saved (Fig. 9). These versions can be downloaded freely from https://bitbucket.org/suunto/movesense-mobile-lib/downloads/ for Android and from the Apple Store for iOS. Finally, one must return to the *DFU* screen and select *Select Device* and choose the device to be used. Once this is done, *Proceed* should be pressed and the update will be done.

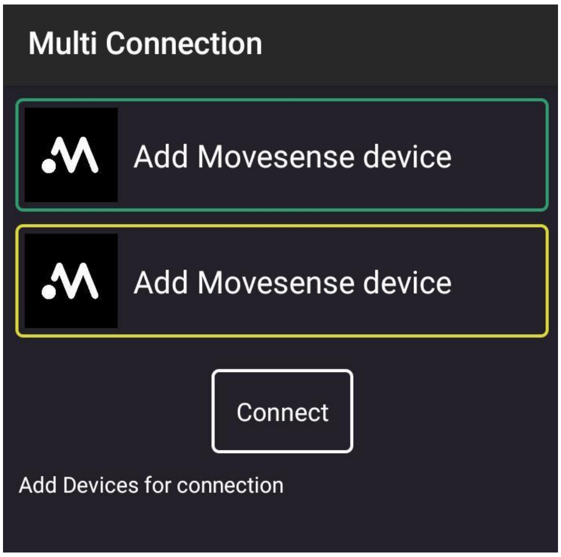


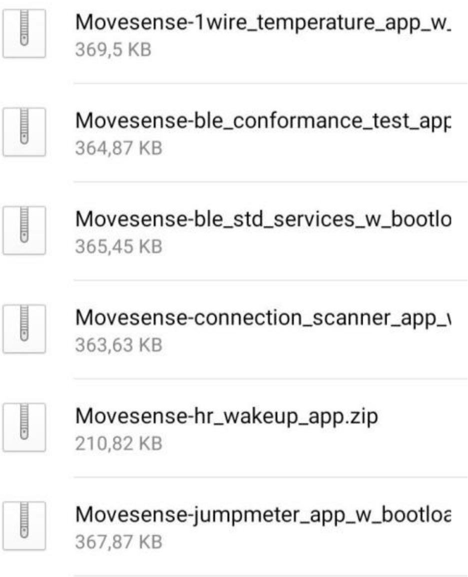
Fig. 7. Multi Connection screen, to add more than one device.

DFU zip Sw Version:

Movesense Sw Version: Device must be connected

Fig. 8. DFU screen, to update the App.

- Saved Data: On this screen all the data in chronological order (from oldest to newest) that has been measured is found. This data is saved as a .csv file and can be transferred online by logging into an email account and performing API configuration or by USB data transfer from the mobile device to the computer (Fig. 10). For iOS Operative System, files are saved as .json and can be converted by the app to .csv files. These files could be updated into the Cloud without configuring the API.



Movesense-1wire_temperature_app_w_
369,5 KB

Movesense-ble_conformance_test_ap
364,87 KB

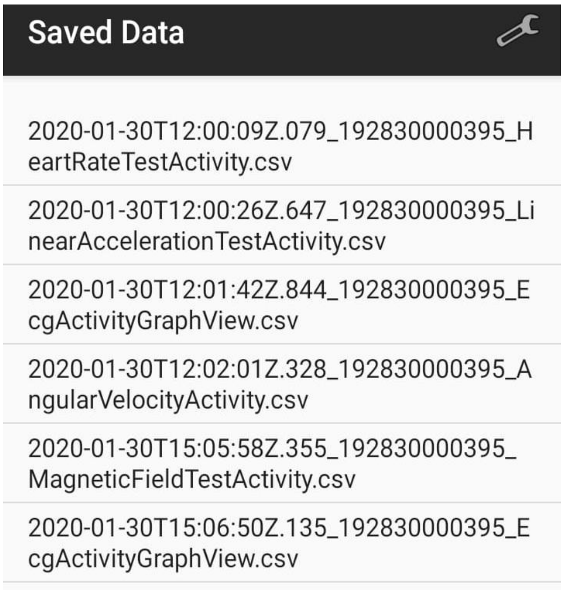
Movesense-ble_std_services_w_bootlo
365,45 KB

Movesense-connection_scanner_app_
363,63 KB

Movesense-hr_wakeup_app.zip
210,82 KB

Movesense-jumpmeter_app_w_bootlo
367,87 KB

Fig. 9. Screen when *Select File* and Storage folder is selected.



Saved Data

2020-01-30T12:00:09Z.079_192830000395_HeartRateTestActivity.csv

2020-01-30T12:00:26Z.647_192830000395_LinearAccelerationTestActivity.csv

2020-01-30T12:01:42Z.844_192830000395_EcgActivityGraphView.csv

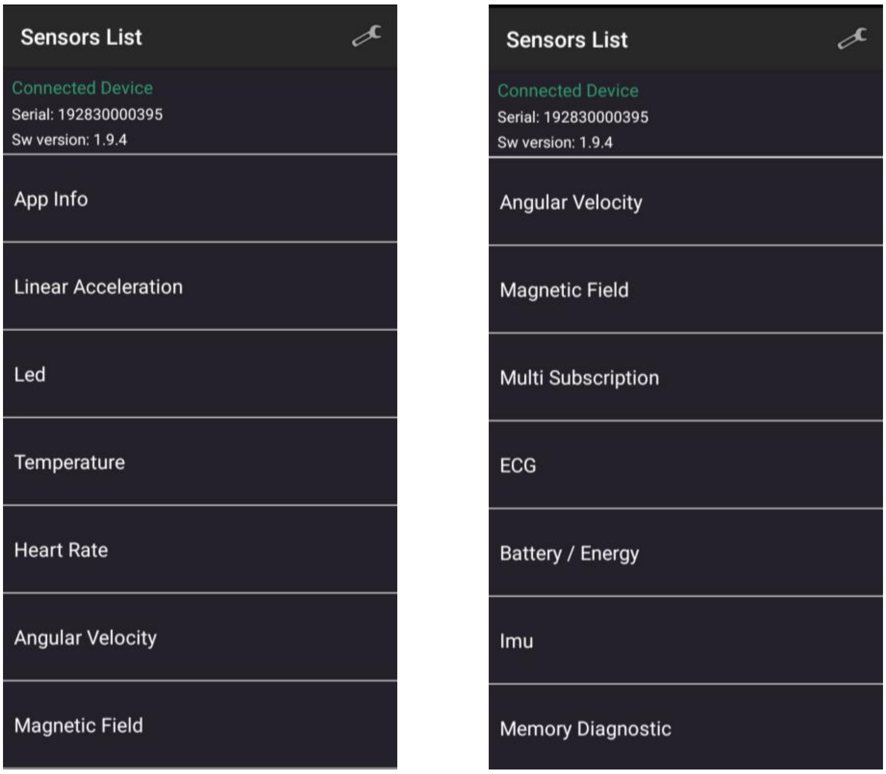
2020-01-30T12:02:01Z.328_192830000395_AngularVelocityActivity.csv

2020-01-30T15:05:58Z.355_192830000395_MagneticFieldTestActivity.csv

2020-01-30T15:06:50Z.135_192830000395_EcgActivityGraphView.csv

Fig. 10. Saved Data screen, where the Data is saved is *.csv* format.

Inside the Movesense panel, once the sensor is connected, there is a Sensors List with the measurements that the sensor can do (Fig. 11). [39]


Connected Device
Serial: 192830000395
Sw version: 1.9.4

Connected Device
Serial: 192830000395
Sw version: 1.9.4

Fig. 11. Sensor Measurements List

- Connected Device: Serial number and software version of Movesense device.
- App Info: Name, version and company provider for software application.
- Linear Acceleration: Acceleration force along the x, y and z axes measured in m/s^2.
- Led: Turn indicator LED on/off.
- Temperature: Temperature in Kelvin and degrees Celsius.
- Heart Rate: Heart rate in beats per minute and distance between RR peaks in milliseconds.
- Angular Velocity: Rate of rotation in radian/s around the x, y and z axes. Rates are same as in Linear Acceleration.
- Magnetic Field: Magnetic field in micro Tesla along the x, y and z axes. Rates are same as in Linear Acceleration.
- Multi Subscription: Subscriptions to three measurement sensors at the same time. There are Linear Acceleration, Magnetic Field and Angular Velocity.

- ECG: Electrocardiogram measurement and live chart. Values reported are in units of count (the conversion factor is 0.6866 $\mu V/Count$) and in Timestamp (milliseconds since the start of the sensor).
- Battery/Energy: Display status of battery in percentage.
- Imu: Single subscription to multiple measurements at the same time. Imu6 for Linear Acceleration and Angular Velocity; Imu9 for Linear Acceleration, Angular Velocity and Magnetic Field.
- Memory Diagnostic: Responses the memory diagnostic with free stacks in memory.

[39]

The previous description is for the device application with an Android operative system; however, the functionality is the same for iOS being the only change the interface with the user and the way to get the data.

The phone used during the project was an iPhone 6s, 16 Gb, version 13.1.4, i.e. with iOS operative system. The version of the Movesense ShowcaseApp application used is 1.9.7 and the library version was 1.39.0. (Fig. 5).

The device used as a sensor was connected to the mobile phone via Bluetooth. Once this was done, the measurements were made in the ECG section of the App and the data was subscribed to obtain the signal. Once the data was obtained, the *.json* files obtained (in the case of iOS) were transferred to the computer and converted into *.csv* files, that was used throughout the study. The characteristics of the computer are in the section Data Processing.

2.2 Subjects

Only one subject was measured in the study because what was pursued was the EMG measurement feasability of the sensor and not the analysis of a behaviour for which more than one subject would be needed. The subject was healthy and without symptoms or motor injuries. The subject was right-handed. The subject was informed verbally about the aim of the project and the right to withdraw at any time of the process according the Declaration of Helsinki. Its verbal consent was given.

2.3 Experimental Design

The muscle being studied is the right *extensor digitorum* (ED), this muscle can be affected by repetitive work with screwdrivers or even writing. It is a muscle that can also be found injured in tennis players and pianists [40]. A single muscle was measured because the study focuses on the capability and feasability of the Movesense. The exact location of the electrodes was found by palpation [9].

The electrodes used are bipolar surface electrodes made of high-quality Ag/AgCl sensor. The distance between the electrodes is 20 mm from the centre of one electrode to the other. The orientation of the electrodes is parallel to the muscle fibres. The preparation of the skin to obtain a better skin-electrode contact used is based on shaving and cleaning with alcohol according to each case. Then, allow the alcohol to evaporate from the skin until dry skin is obtained [26], [41].

Two experimental designs were performed. The first one, a way to discover how the signal should be measured to verify that electrodes with Movesense sensor HR+ should be the best way. The second one, an experiment to discover if this method could be suitable for being a future cheaper solution to measure the EMG signal. Fig. 12 explains with a diagram the following experimental designs to clarify them.

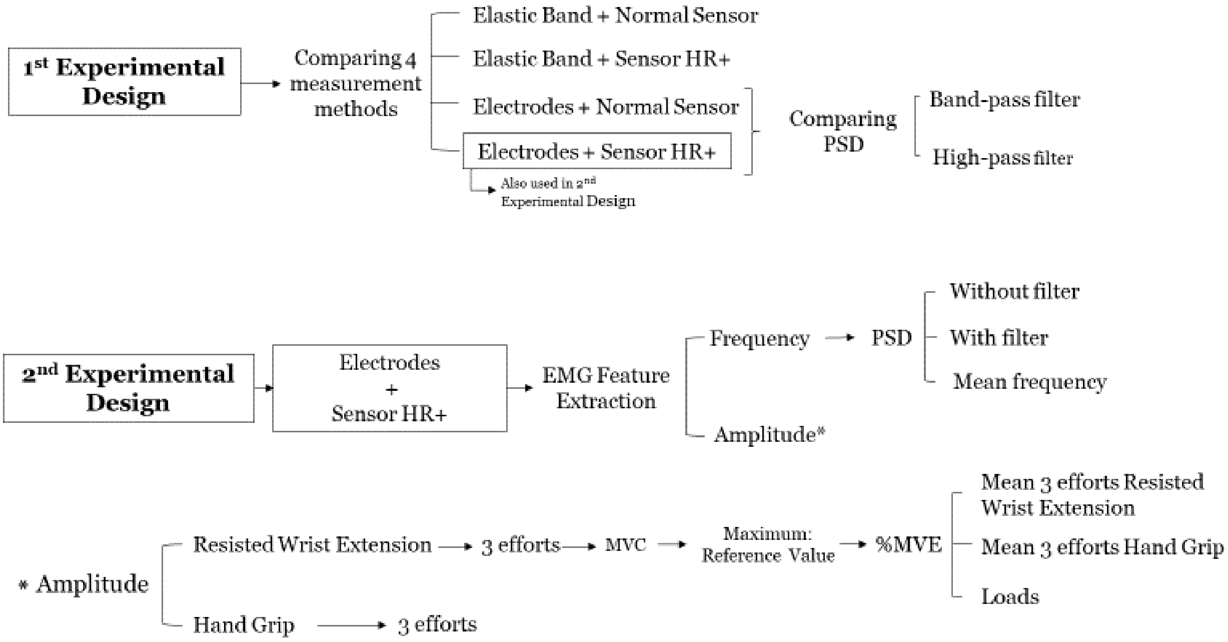


Fig. 12. Diagram of the experimental designs.

- **First experimental design:** The signal was obtained by 15 s of maximum effort with a 3 kg dumbbell and rests between exercises of 30 s. The participant was seated in a standard position with the elbow at 150° approximately, without support in the hand or forearm and with a neutral position at the wrist this is shown in Fig. 13 [6]. This exercise was performed four times in different ways. The first of these was carried out with the HR+ sensor and the electrodes in place. The second one with the Movesense sensor (not HR+) and the electrodes. The third way was with the HR+ sensor and an elastic band. The fourth, with the sensor (not HR+) and the elastic band. The placement in shown in Fig. 14. All the ways were measured by 512 Hz sampling frequency.

Fig. 13. The electrodes and the sensor with the developed wire structure.

Fig. 14. Placement of the sensor with the electrodes (left) and with the elastic band (right).

- **Second experimental design:** To analyse the feasibility of the Movesense sensor, three maximal efforts of 5 seconds and a subsequent 30 second total rest were first calculated with a *resisted wrist extension* method. The exercise was performed with the person sitting with arm and wrist supported on the table while the hand was off the table. The subject was asked to perform maximum wrist extension while having an effort downwards the back of the hand while the wrist remained in a neutral position [7]. The rest was done while the hand was totally supported by the table. Care was always taken to ensure that the wrist remained in a horizontal position while the wrist extenders were maximally activated. The arrangement of the subject is shown in Fig. 15.

  After this exercise, from which the rest and the MVC mean were obtained, in addition to the maximum peak MVC. The maximum MVC mean was the maximum of the 3 efforts done, this value was used as a reference in order to normalize the signal to %MVE (eq. 6). The rest mean was obtained by the mean of the value while the hand was on the table with no activation. As a plus, the same exercise was done with a *hand grip*, a manner used by many research groups to obtain the MVC of the forearm muscles in a neutral forearm posture, for comparing both methods and having the %MVE of *hand grip* referencing on the *resisted wrist extension* method as seen in [7] Once the exercises had been carried out to obtain the reference values, the effort made by the wrist in the same position with different loads placed on the upper part of the wrist continued to be measured. The loads used, with the hand weight added, were 3.3 kg, 1.8 kg, 1.3 kg, 0.8 kg and 0.3 kg., being this last one known as the hand weight. Knowing the difference between the amplitudes helped us to know the validity for occupational measurements.

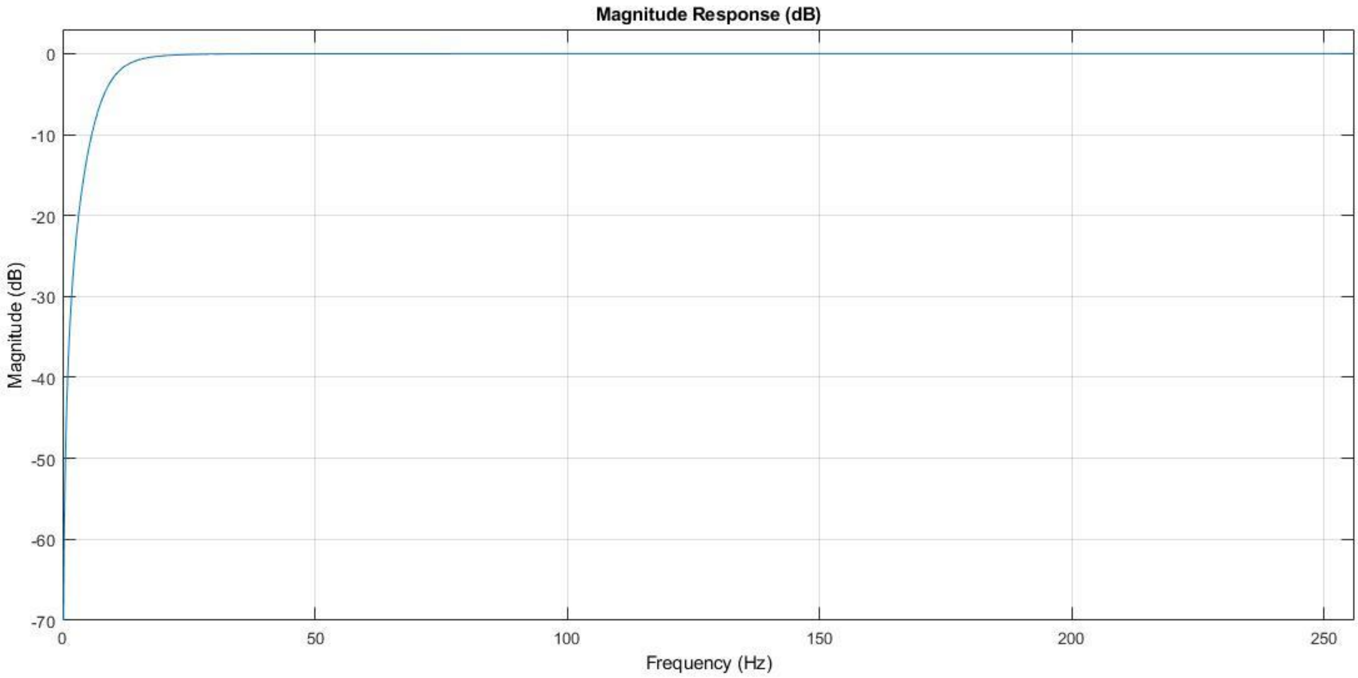
Fig. 15. Placement of the arm and the wrist during the second experiment and where the load was placed.

2.4 Data Processing

The computer used had Windows 10 Home (© 2019 Microsoft Corporation) with a 64-bit operating system, x64 processor. The program used to process the raw EMG data was MATLAB (Mathworks, ® (MathWorks Inc., Natick, MA, USA)) version R2019b.

The EMG files were obtained in *.json* format and converted into *.csv* format. This file was read as having two columns, one called Timestamp that consists of the time in ms since the sensor was started and another called Amplitude that was used to obtain the Voltage in mV. The obtained signal already contained filters added in the Movesense sensor code, however, this one was digitally filtered with a fourth order Butterworth high-pass filter, with 10 Hz first corner frequency for the motion artifacts and a band-pass filter was used for the normal sensor with two corner frequencies, one at 10 Hz and another at 200 Hz. In addition, these filters help centring the signals. The sampling rate used was 512 Hz. The filters are shown in Fig. 16.

For the first experiment, the signal was only filtered, but for the second experiment the signal was more analysed for knowing if this method would be a suitable way to get the signal. So, for the first experiment, the sEMG obtained with the sensor HR+ was only high-pass filtered while the sEMG obtained with the normal sensor needed to be band-pass filtered. Its power spectral density (PSDs) were calculated to know the effect of the filter. By equation 4 the mean frequency of the signal was calculated.



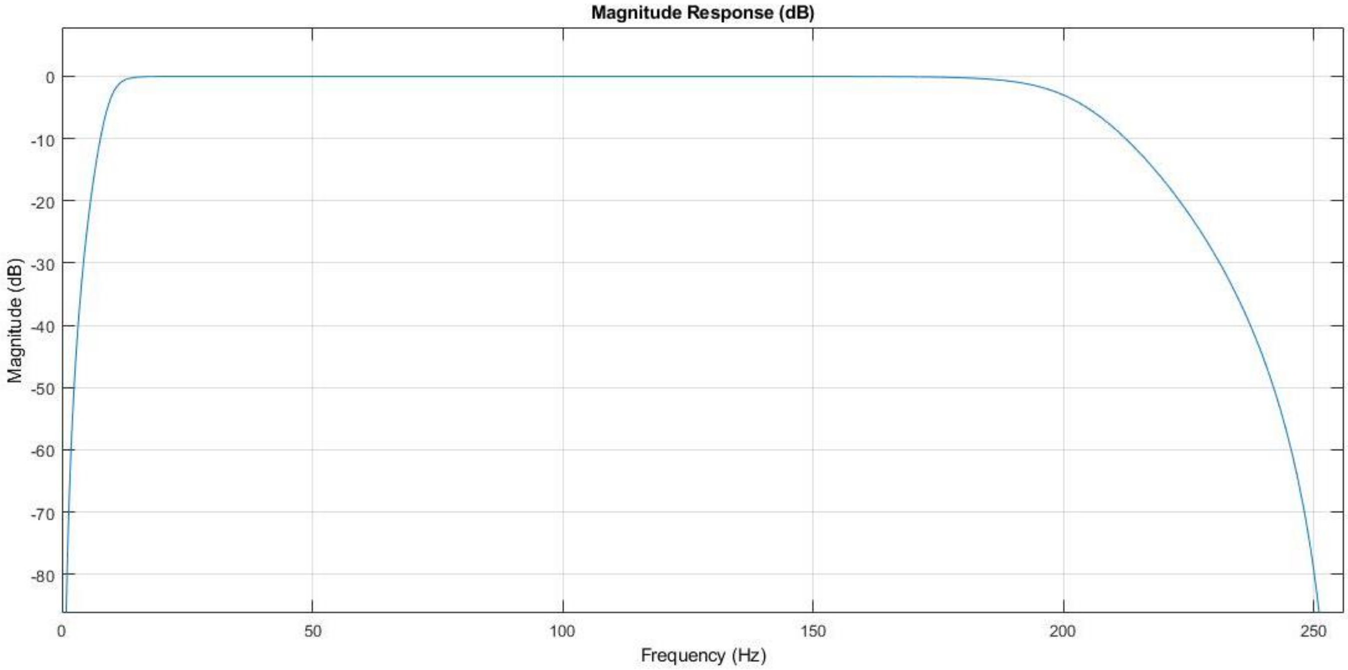


Fig. 16. Above: Applied high-pass filter. Corner frequency at 10 Hz.
Below: Applied band-pass filter. 1st corner frequency at 10 Hz,
2nd corner frequency at 200 Hz.

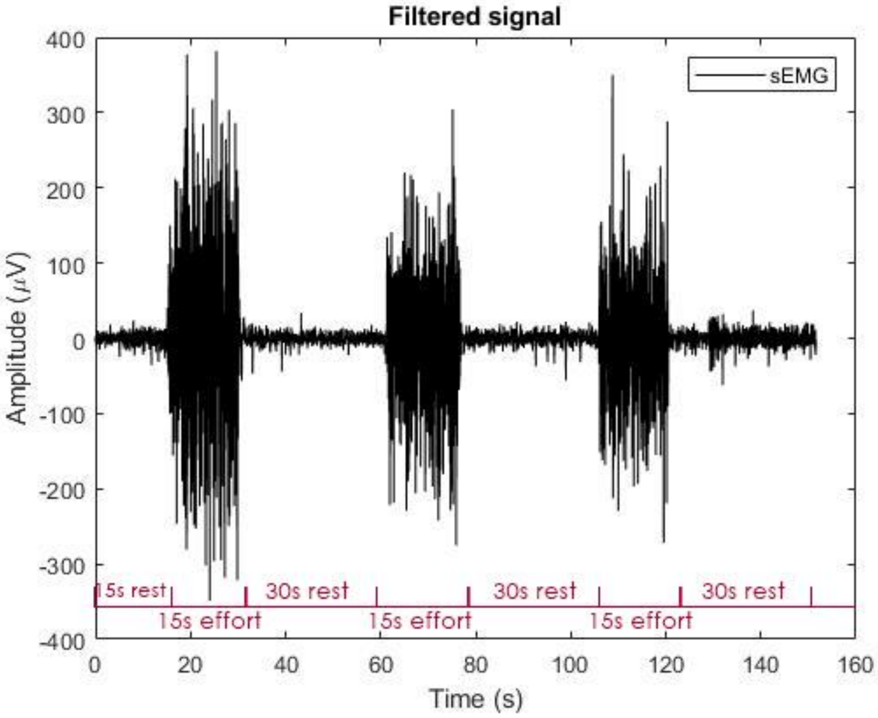


Fig. 17. Parts of the filtered sEMG on the first experimental design. As shown, first there was a 15 s rest and after that a 3 repetition of 15 s effort and 30 s rest.

After that, on the second part of the project, the filtered signal was rectified and then, the average of the rectified was done. The size of the window was obtained by dividing it by the number of windows that were desired, in that case were 12 windows. The time-window used was approximately 1.7 seconds. By equation 2 the Average Rectified Value was obtained.

On the other side, by equation 1 the Root-Mean-Squared Value was obtained. This last value is used for calculating the MVC mean and rest mean, i.e. for obtaining the EMG amplitude. The MVC for each effort and load was calculated. Each signal was normalized considering the reference values (rest mean and MVC mean of the maximum value of MVC from *resisted wrist extension*) and then %MVE was calculated for each load depending on these reference values.

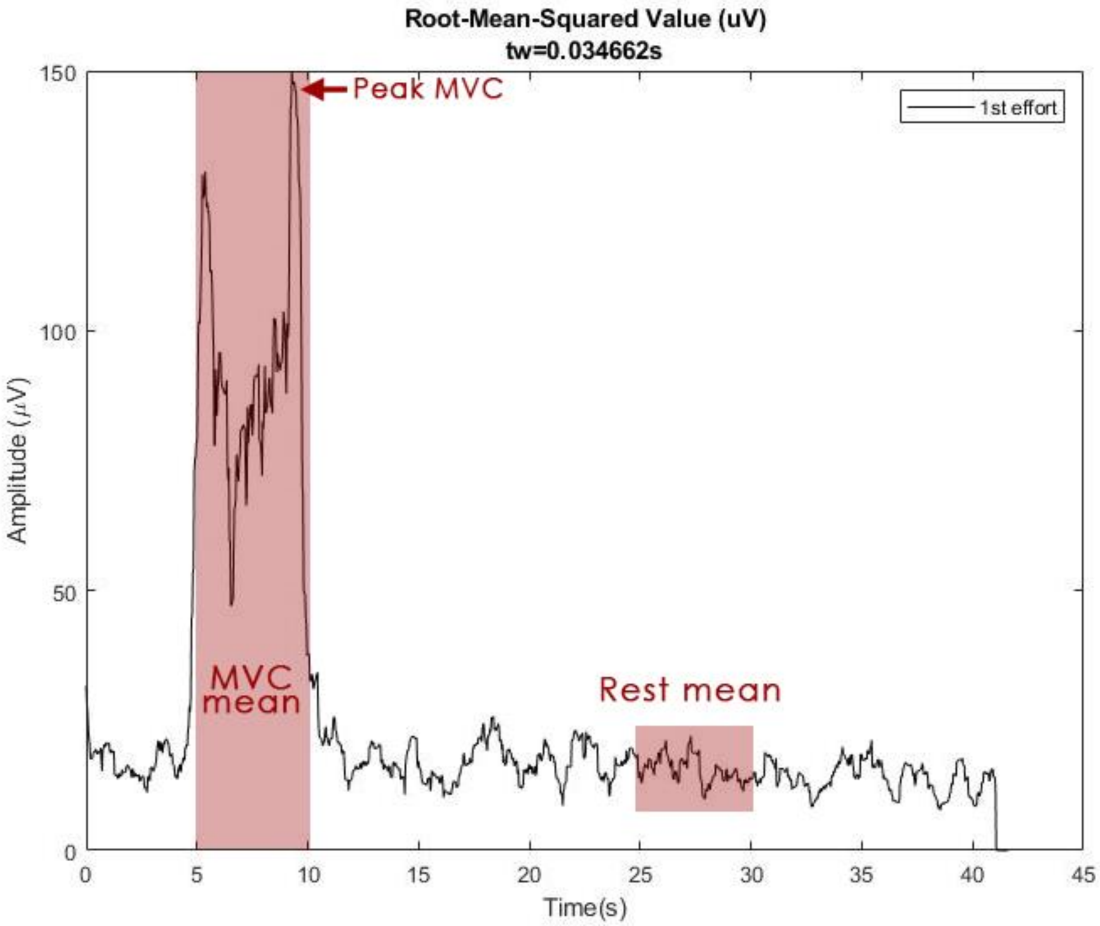


Fig. 18. Example of how MVC mean and rest mean was measured on the second experiment. As it shows, the MVC mean is the mean of the 5 second maximal effort done. The rest mean is a 5 second mean of the hand resting on the table, i.e. without any activation. The peak of the MVC is the maximal amplitude reached by the muscle.

3. Results

Following the **first experimental design**, the signals obtained by the different four methods are shown in Fig. 19 and Fig. 20. The methods were divided into Elec-HR+, Elec-normal, Band-HR+ and Band-normal.

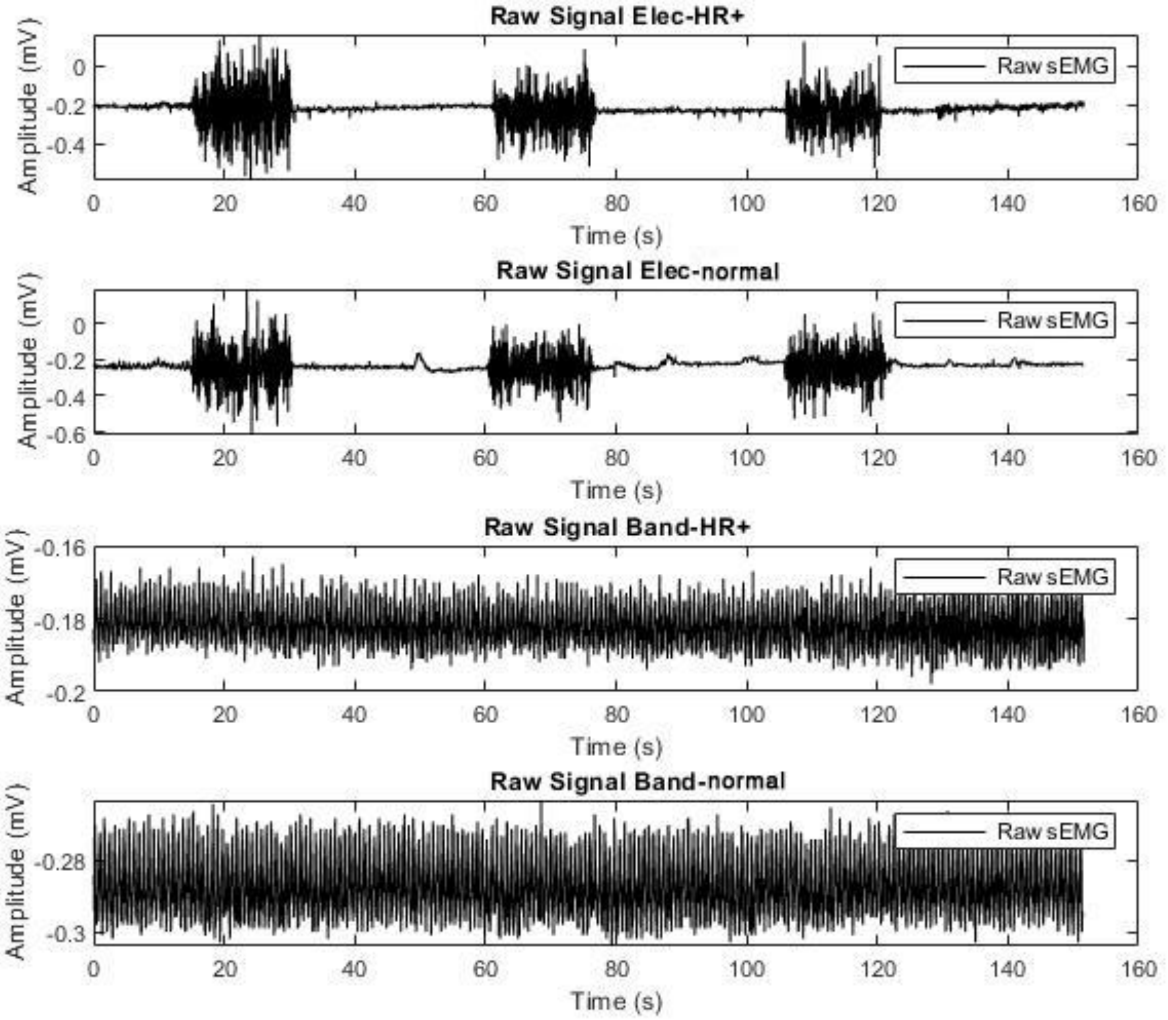


Fig. 19. Raw signals of the four measurements methods at 512 Hz sampling rate.

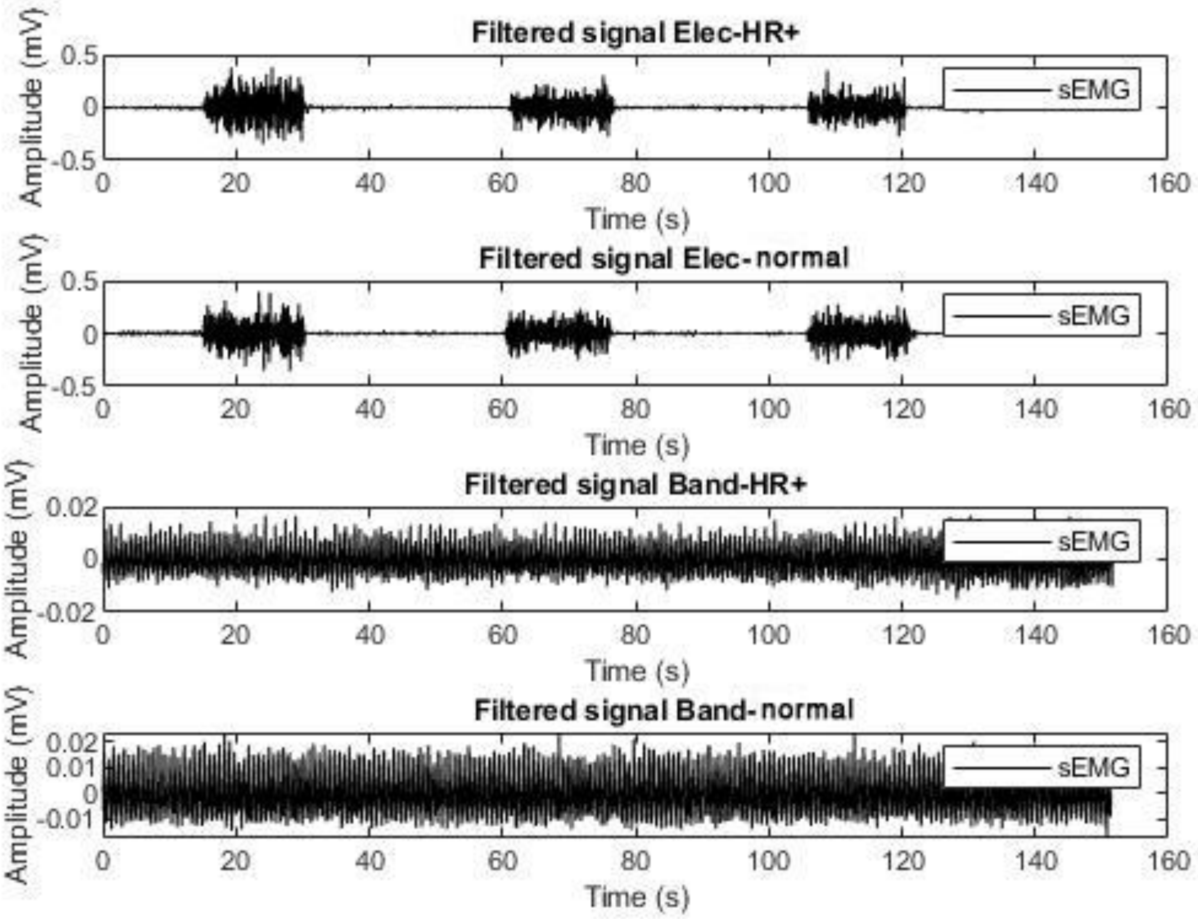
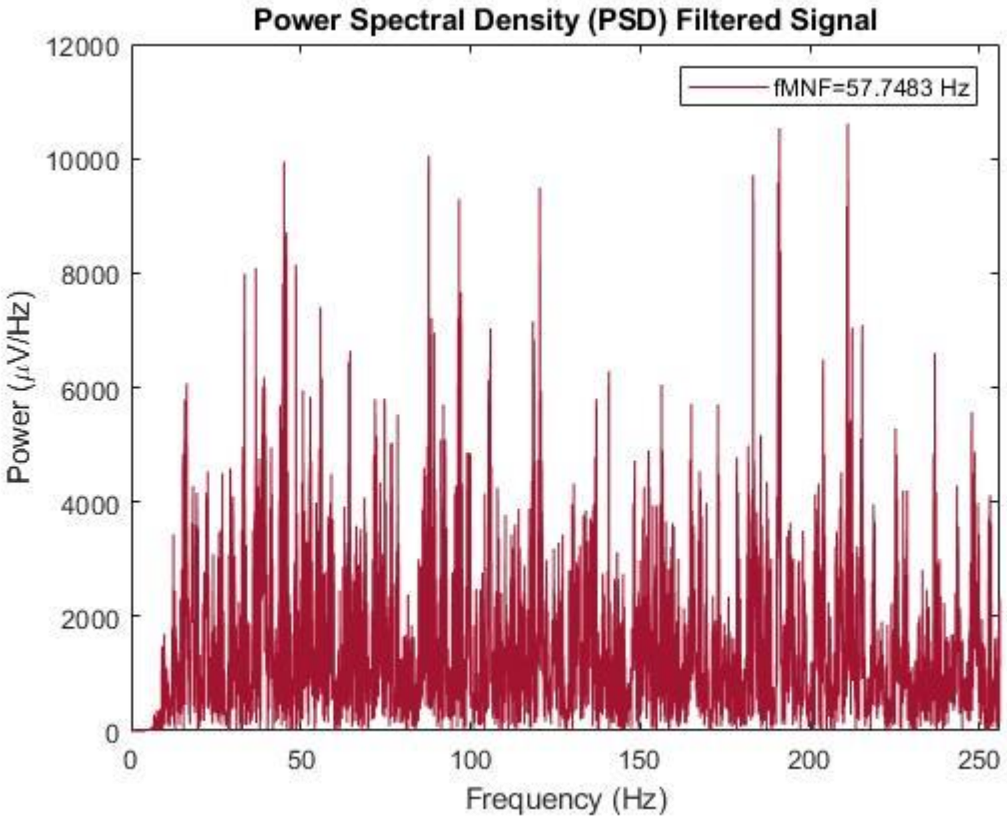


Fig. 20. High-pass filtered signals of the four measurements methods at 512 Hz sampling rate.

The signals obtained with the elastic band were too poor so the signals used were the ones obtained with electrodes with the sensor HR+ and the normal sensor. For analysing these two signals, the PSD and the mean frequency of each one were observed (Fig. 21). Then, a pass-band filter was used in the sEMG obtained with the normal sensor.



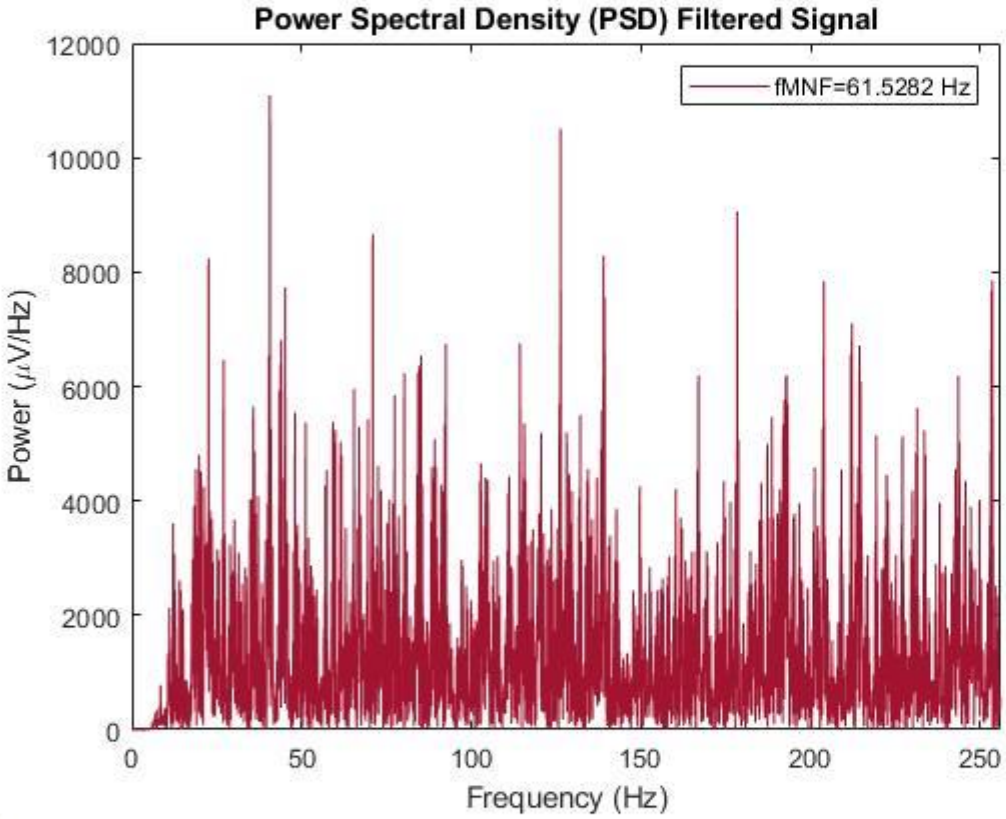


Fig. 21. Above: PSD of the sensor HR+ and its mean frequency. Below: PSD of the normal sensor and its mean frequency.

Figure 21 shows that higher frequencies exists in PSD of the normal sensor so a band-pass filter is needed. The filtered signal with the band-pass filter is shown in Fig. 22 and the effect on the PSD is shown in Fig. 23.

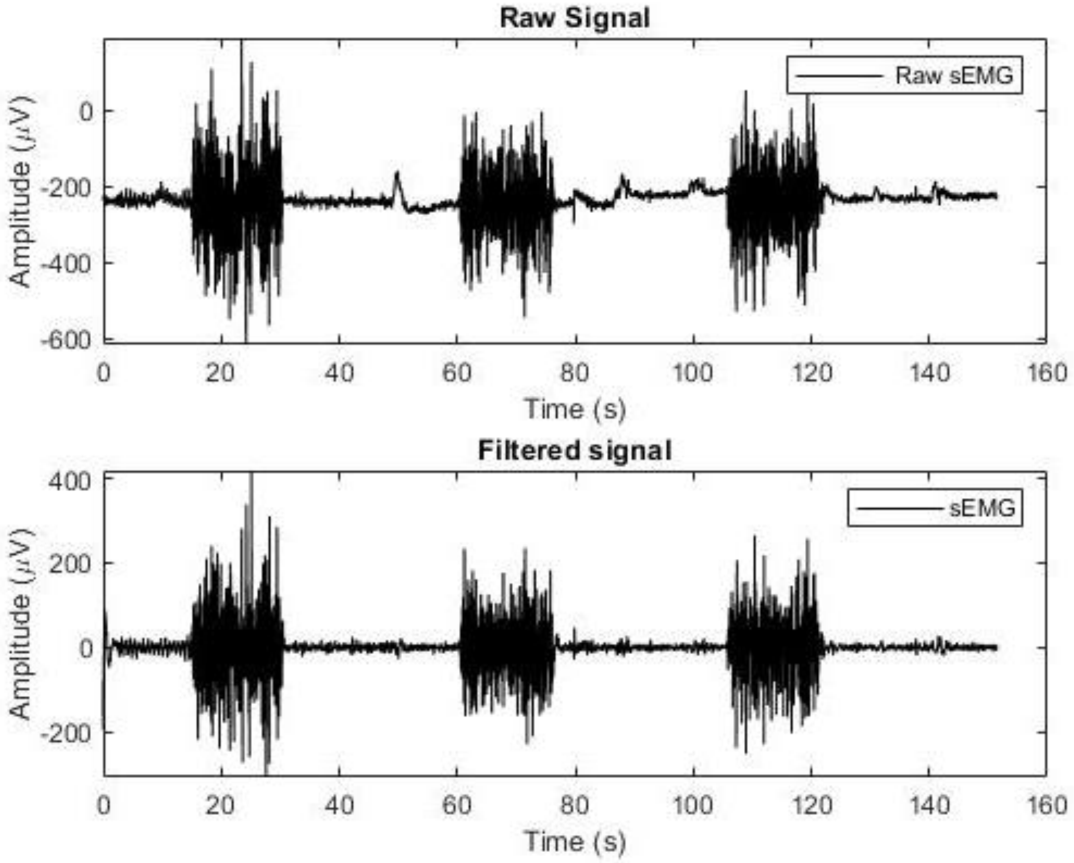


Fig. 22. Raw signal and band-pass filtered signal.

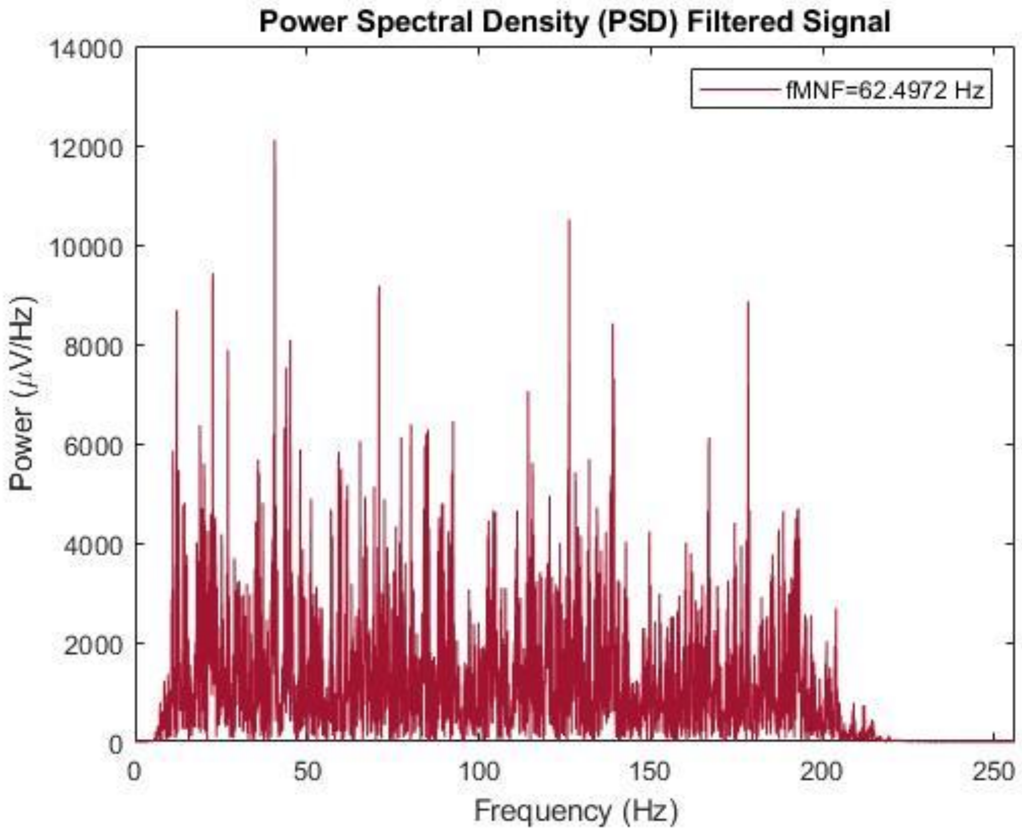


Fig. 23. PSD of the band-pass filtered signal obtained by electrodes and normal Movesense sensor.

Once the measurements were done by the four different measurement methods, the method of the chosen signal, i.e. the filtered signal measured with electrodes and the Movesense sensor HR+ at 512 Hz sampling rate (Fig. 20), was used for the second experiment.

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Following **the second experimental design**, the first of the three maximum efforts was analysed to show how the parameters were obtained.

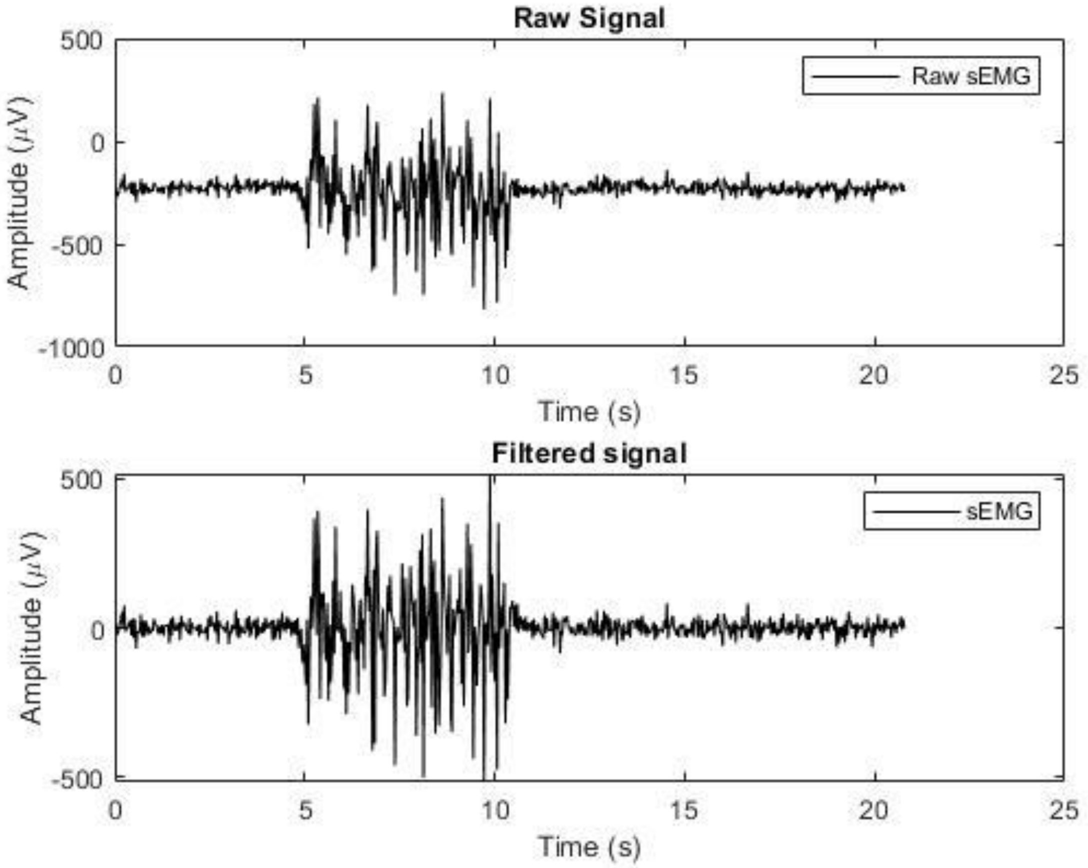

Fig. 24. Raw and filtered EMG of the first effort

In figure 24, the EMG in MVC was between ±500 μV. The sEMG was recorded in 20 seconds. Also, the filtered signal is centred in comparison to the Raw signal. Another way to show the effect of the high-pass filter is with the PSD.

The signal before the filter had a high power on the low frequencies, after the filter, the highest powers on the low frequencies were filtered and then, the lower powers could be seen (Fig. 25).

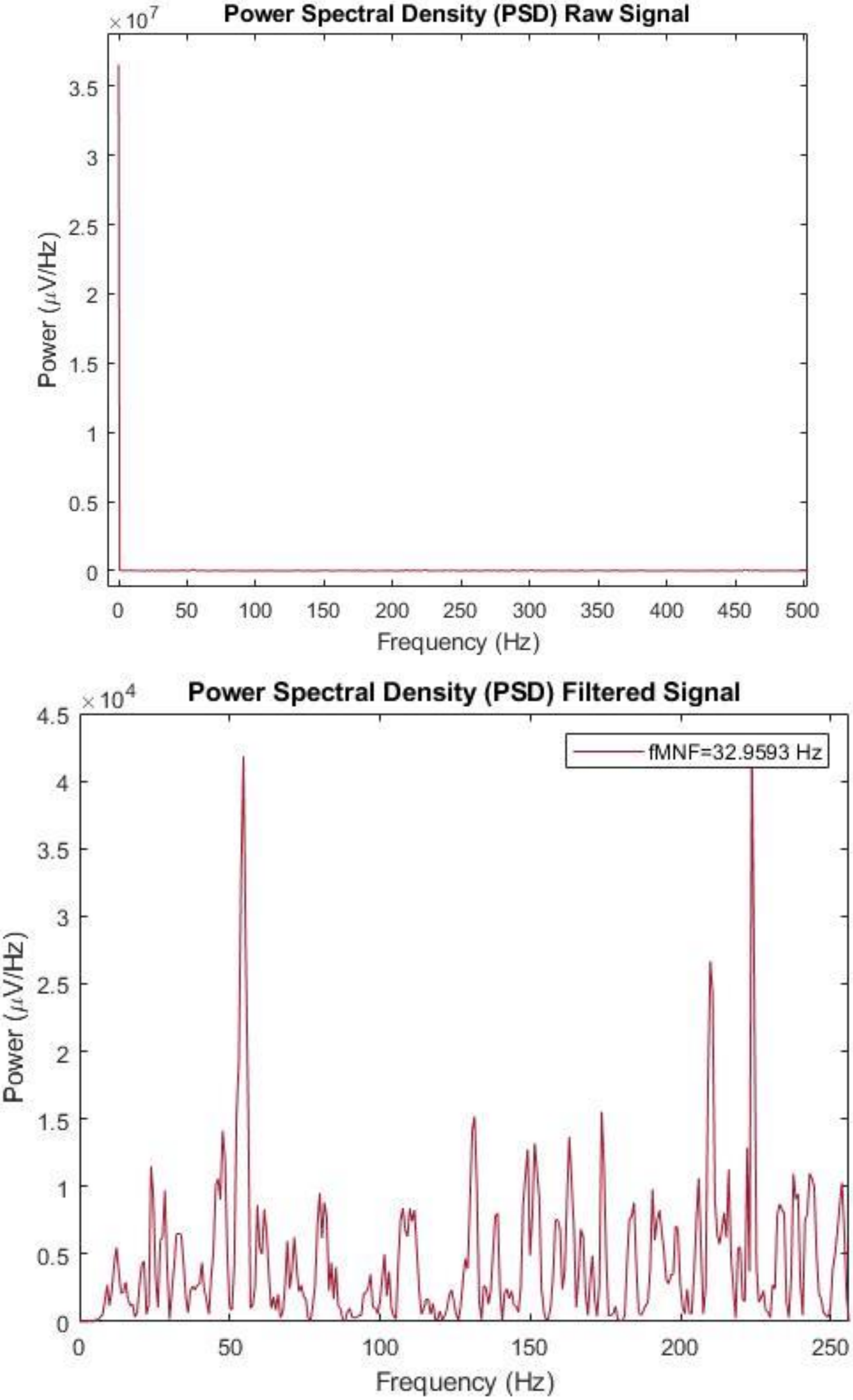

Fig. 25. Above: PSD of raw EMG; below: PSD of filtered EMG with f_{MNF} of all signal. Both with sampling rate of 512 Hz.

After knowing the effect of the filter, the amplitude of the signal was analysed by equation 1 and equation 2. First, the average rectified value (ARV) was calculated by the filtered EMG with a first step doing the rectified and finally calculating the ARV with a time-window of 1.73 s (Fig. 26).

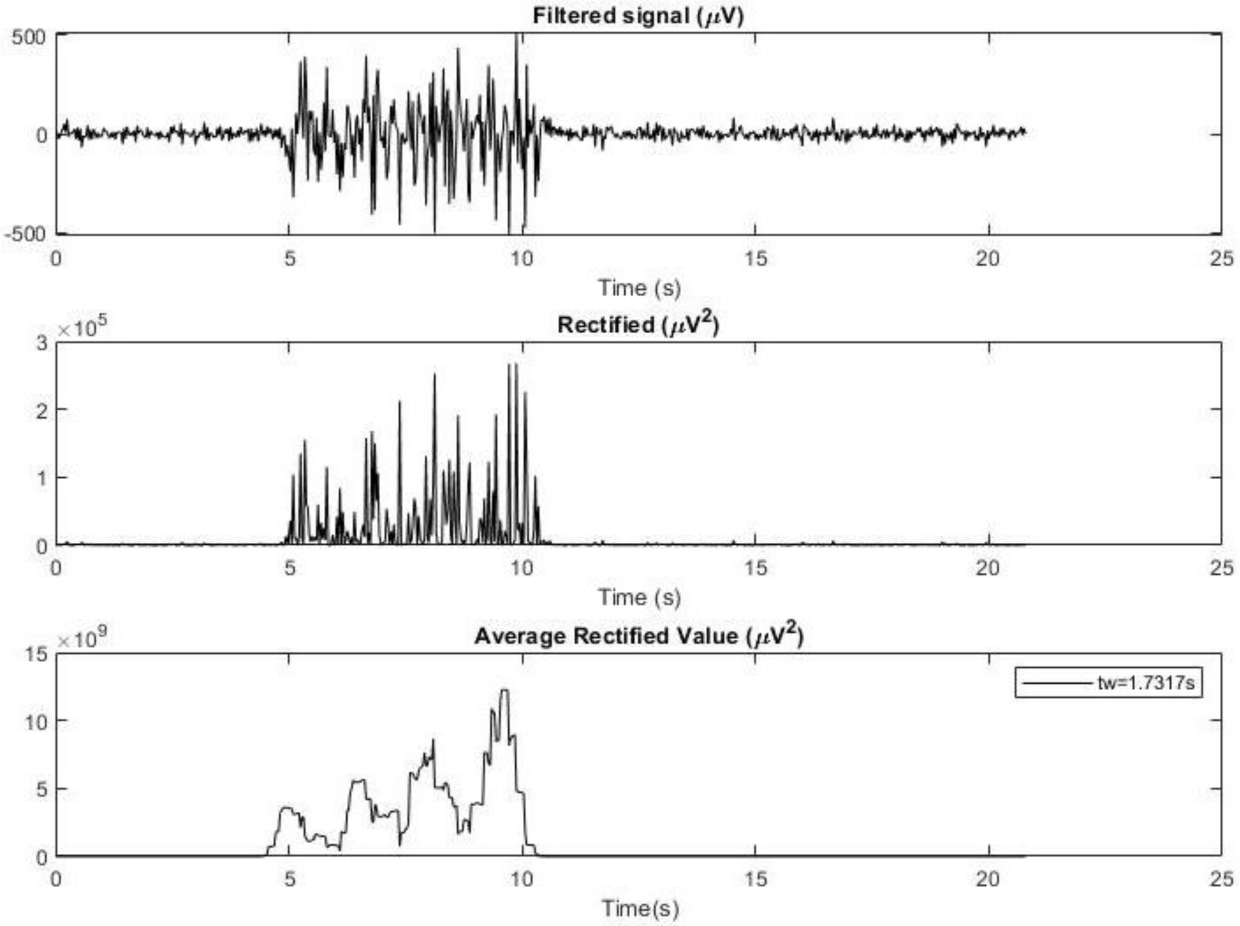

Fig. 26. Filtered signal, Rectified and Average Rectified Value with a time-window of 1.73 s for the 512 Hz sampling rate signal

The rectification mode the signal be in positive values. Then, the ARV did the evolvement of the signal. The bigger the time window, the smoother the evolvement of the signal.

Following the previous step, the RMS was calculated for the chosen signal with different time-windows as shown in Fig. 27. The RMS also return the sEMG in positive values, and as stated above, the bigger the time window, the smoother the evolvement of the signal.

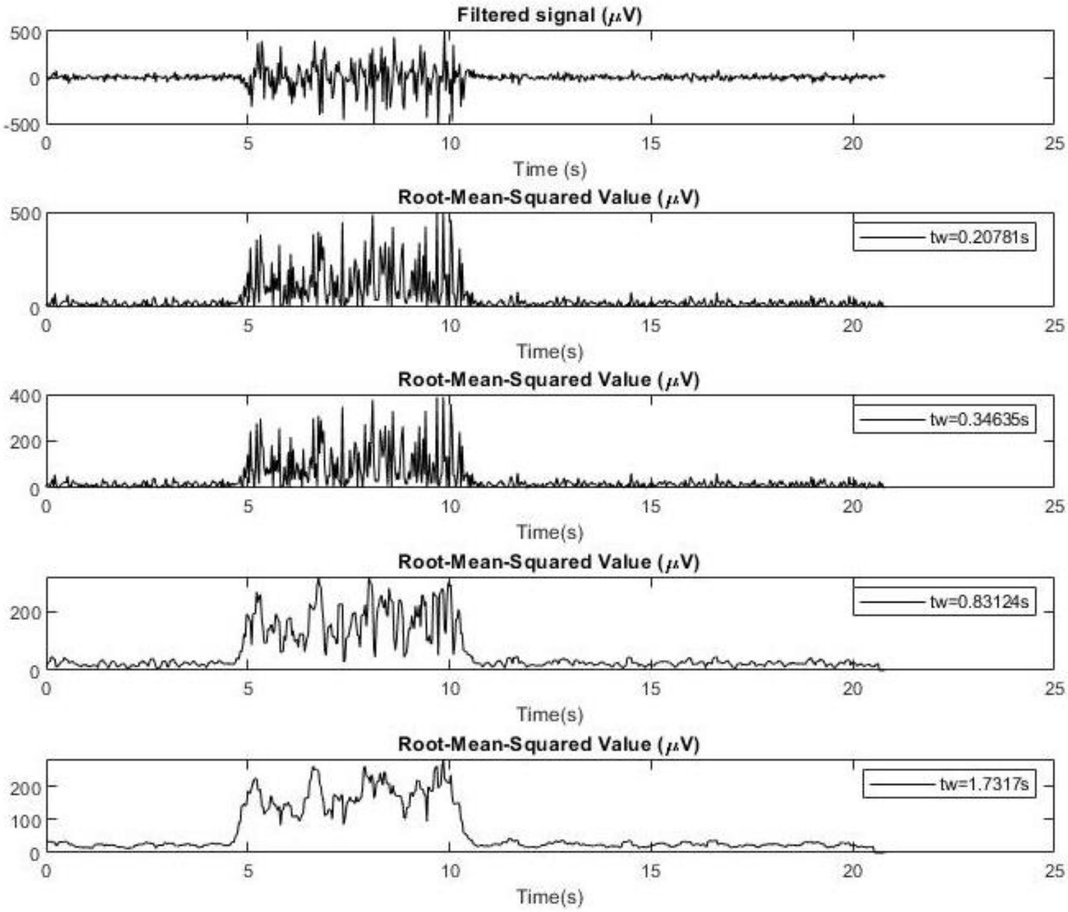

Fig. 27. Filtered signal and various RMS with different time-windows. Time windows were, respectively, 0.21 s, 0.35 s, 0.83 s, 1.73 s.

After calculating the different RMS, the selected RMS was the one with the larger time-window, i.e., 1.73 s. With this RMS, the MVE was calculated by the equation 6 normalizing the signal from the maximum of the 3 efforts and from the rest value shown in Table 1 (Fig. 28).

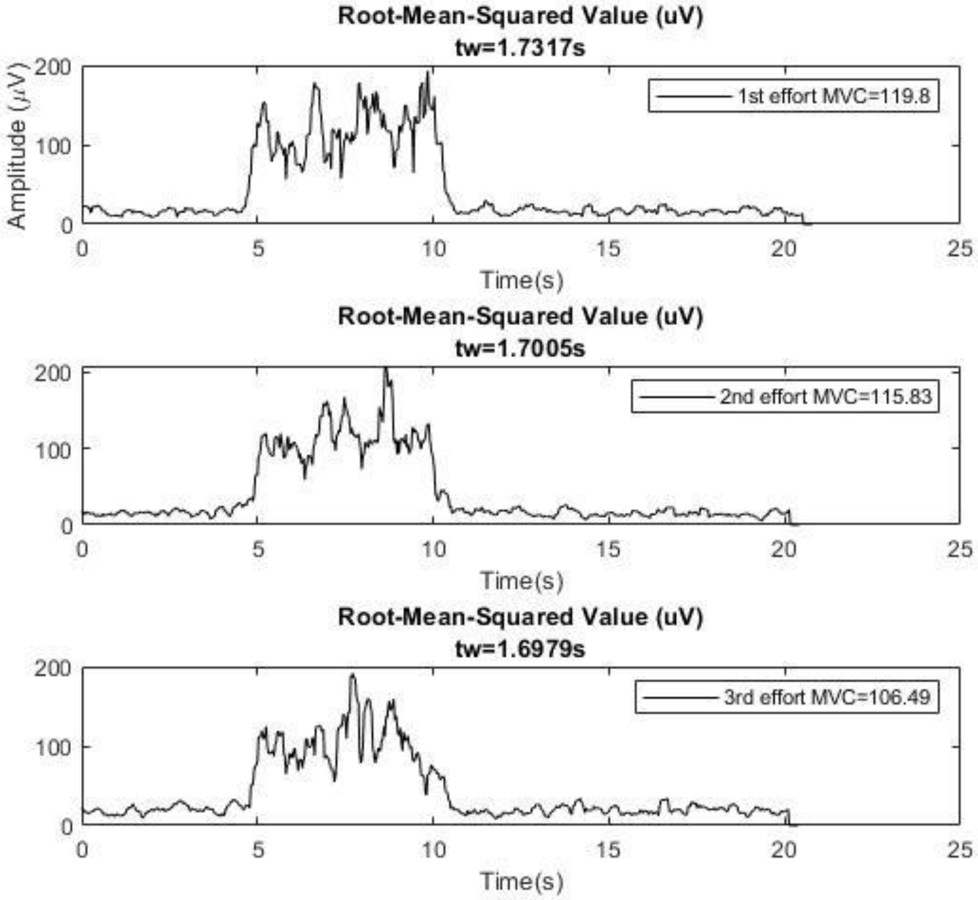

Fig. 28. Three efforts done with its MVC. Done with *resisted wrist extension* method.

	MVC (μV)	**Mean MVC (μV)**	**SD**
RESISTED WRIST EXTENSION	**119.8**	114.04	6.83
	115.83		
	106.49		
HAND GRIP	**MVC (μV)**	**Mean MVC (μV)**	**SD**
	70.16	84.2	12.16
	91		
	91.44		

Rest (μV)	**3.97**

Table 1. MVC for each effort measured in two different methods: *resisted wrist extension* and *hand grip*. Mean of the three MVC calculated and its standard deviation for each method. Rest value calculated in a resting position.

The maximum MVC of the three efforts was 119.8 μV and the rest measure was 3.97 μV. In addition, the noise level was calculated as the minimum of the rest signal and was 0.0052 μV.

Then, the signals analysed were the ones done with the loads. The three different occasions were repeated with different load order. First, it shows all the data extracted on Table 2. Also, some charts were plotted for a better analysis of the signals.

EMG$_{amp}$ (μV)					
LOADS	**1st time**	**2nd time**	**3rd time**	**MEAN MVC (μV)**	**SD**
3.3 kg	63.95	71.49	92.35	75.93	14.71
1.8 kg	46.5	29.56	35.81	37.29	8.57
1.3 kg	26.87	26.39	25.25	26.17	0.83
0.8 kg	20.91	24.33	18.18	21.14	3.08
0.3 kg	16.34	11.29	16.21	14.61	2.88

Table 2. EMG amplitude for each different occasion with five different loads. The loads used were 3.3 kg, 1.8 kg, 1.3 kg, 0.8 kg and 0.3 kg. All these loads include the hand weight (0.3 kg). Mean of MVC for the three different times for each load and its standard deviation.

Figure 29 shows a bar chart with the MVC normalized into %MVE. The reference value was the maximum of the three efforts done and also the 100% of MVE. The figure reveals an ascending tendency as bigger is the load. Being the lowest %MVE the hand without any load, just having its own weight (0.3 kg) as 9.19% and the biggest the load (3.3 kg) with the biggest %MVE, 62.13%. The mean of the efforts of the *Resisted Wrist Extension* was the 95.03 % from the reference value. Also, the plot showed that the mean of the *Hand Grip* efforts was 69.27%.

Figure 31 shows a boxplot of the loads with the 3 occasions measured. It shows an ascending shift with the same result as in Figure 29.

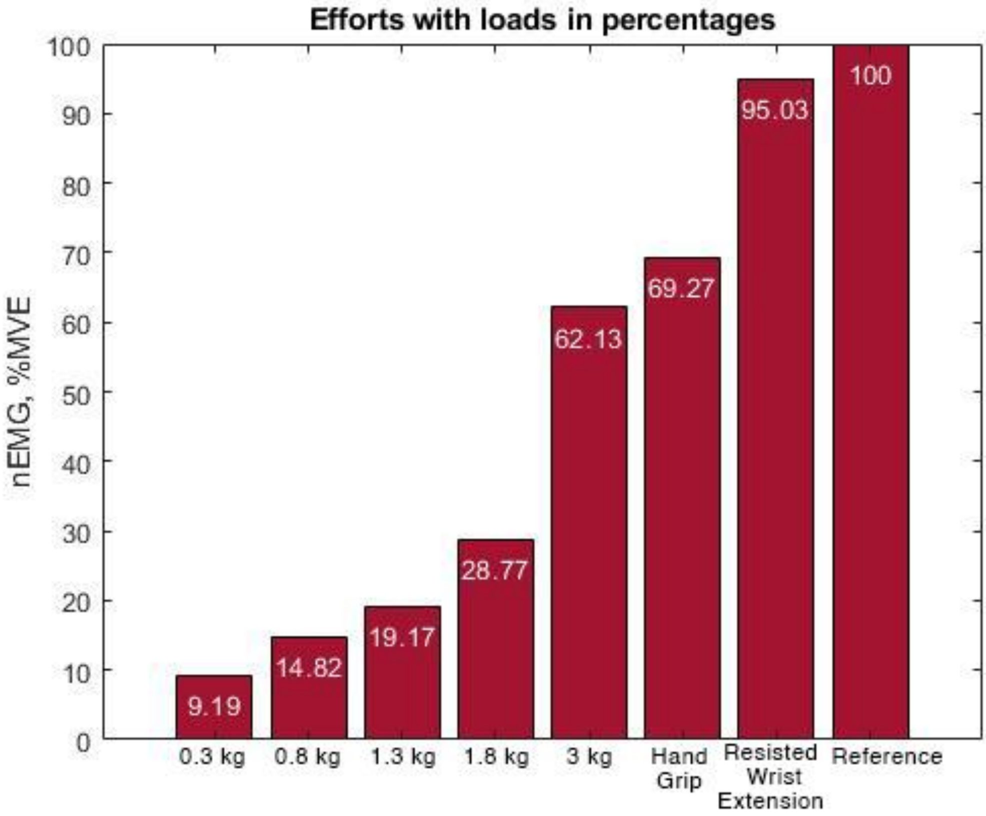

Fig. 29. Bar chart of %MVE of the different loads. Reference value as the maximum of the three first efforts done.

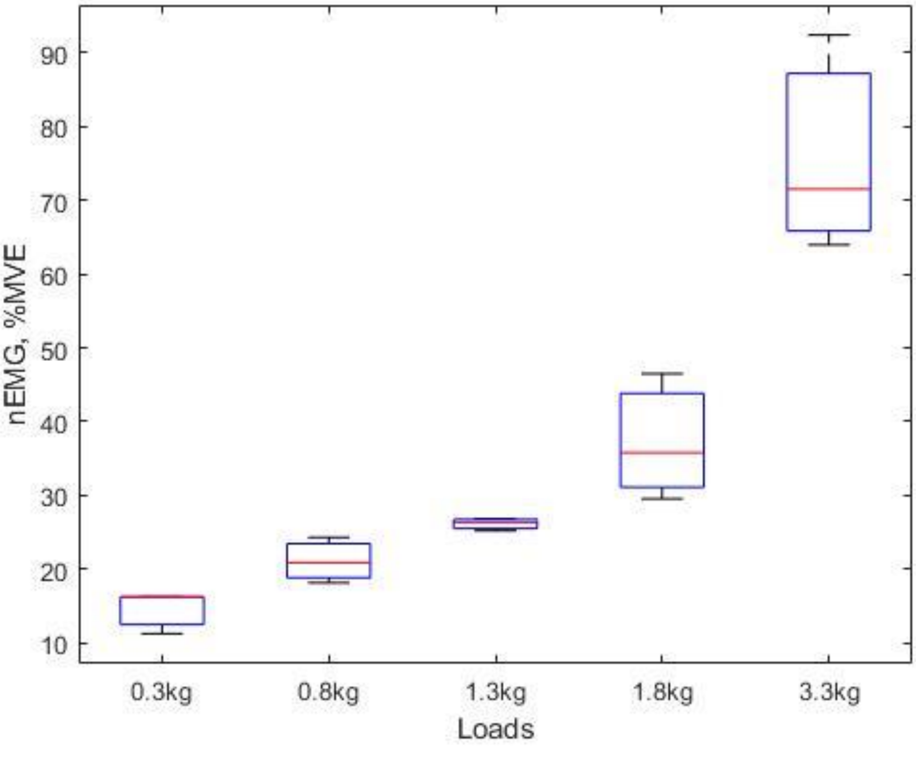

Fig. 30. Boxplot chart of %MVE of the different loads.

In figure 31, correlation between %MVE and weight is analysed. It is shown statistically how there is a linear increasing as the load is bigger. The linear equation has an R^2 of 0.97. Also, observing line with red points, it shows there is a bigger slope as bigger is the weight.

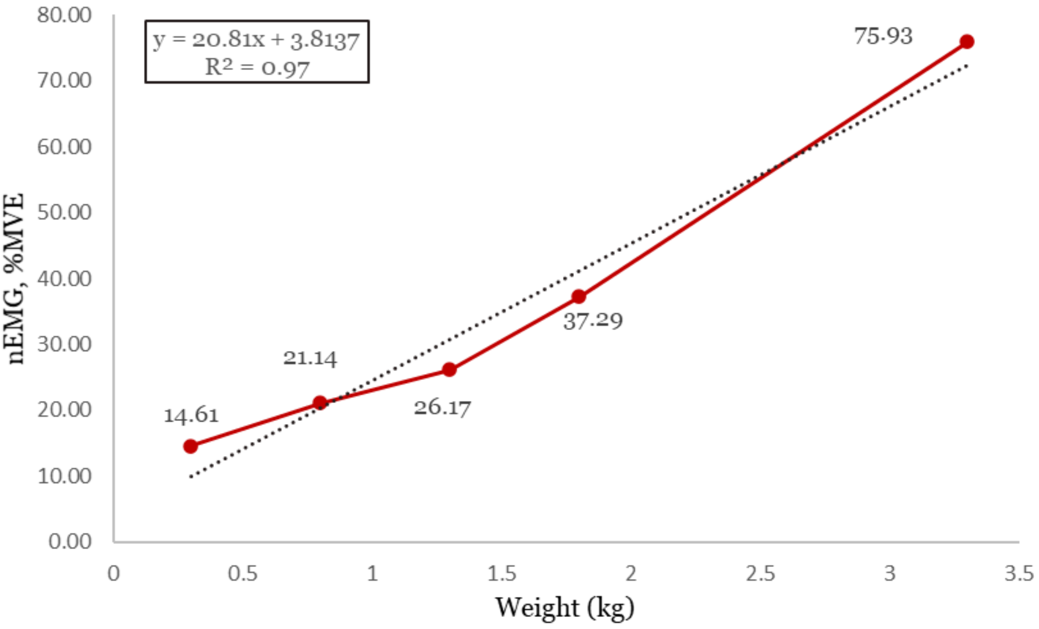

Fig. 31. Statistical analysis, correlation between %MVE and weight.

4. Discussion

First of all, regarding the measurements, the sampling frequency used for doing the measurements was lower than the recommended by [26]. The sampling frequency was 512 Hz, almost the middle of the recommended, and this could be one of the factors for a lower resolution on the signal or the values obtained by the sensor.

On the **first experimental design**, as was assumed for the start, the best signal acquired was the one with the electrodes and the sensor with the HR+. The signal that the elastic band gave was poor for both sensors, that meant that the signal obtained with the electrodes was well obtained and this confirmed that the electrodes should be connected into the sensor screws.

Also, in Fig. 19 it is shown a little curve on the signal between the efforts that was deleted with the first filter (high-pass). Although the raw signal was better than the one obtained by the Movesense sensor HR+. Also, looking at each one PSD, bigger frequencies appeared on the normal sensor, that confirmed that HR+ had filters and amplifiers to have a better measure in muscle signals inside the sensor and the normal sensor needed an additional band-pass filter.

After analysing the results on the first experimental design, the **second experimental design** is discussed. When the signals in this part of the project were filtered, the signal was improved. In EMG plots this was not so clear but looking at PSD this was more perceptible. In PSD there were low frequencies with big powers, that mode the PSD not possible to analyse, but when the signal was high-pass filtered these big powers on lower frequencies disappeared [11]. These frequencies should belong to muscles as seen in [11], [14]. Also, it was estimated that the high frequencies level off in the PSD, although, it is possible that these frequencies were there because of the small sampling rate or also because the EMG amplitudes were not obtained at the level expected. The results obtained in Mean Frequency are not as high as obtained for similar values in [24].

The ARV was calculated but it is not a common way of analysing amplitude nowadays. However, currently, the method commonly used is RMS. Different tw were calculated and the tw that best fitted was 1.73 s, it achieved a smoother signal and also the biggest MVCs.

The MVCs obtained were lower than MVCs measured on [7], [13] and these values should be the ones obtained as said in [42], i.e. the amplitude should be 4-5 mV_{pp} approximately, because same muscle is measured. But rest value was well obtained (3.97 μV) due to the range seen also in [42], i.e., in the range of 2 to 10 μV_{pp}. The reason of the lower EMG amplitudes could be due to the connection between the electrodes and the sensor, this could be solved by a lower distance between electrodes and sensor or also a better wire conductor. Another artifact that could affect could be interferences with the skin or other kind of noise. All of these were tried to avoid along the development of the project.

More problems that could have interfered was the lack of experience using this device. Last reason, but less likely, could have been a muscular disease that was not detected. However, the analysis showed that in comparison between different loads, results obtained seemed to be right. That is because there was a bigger effort when holding a 3.3 kg load than a 0.8 kg load.

In Fig. 29 was increasing as bigger was the load. Also, as said in [7], it was demonstrated that *resisted wrist extension* method gave bigger MVCs than *hand grip* method. Because of that, this method should be used for this kind of investigations, i.e, for muscles as *extensor digitorum* or experimental designs similar as the one developed on this thesis, analysing the amplitude.

In Fig. 30 could be seen that there was a greater variance in bigger loads as in 1.8 kg and 3.3 kg and smaller variance appeared on lower ones. However, measurement values done on 1.3 kg were the nearest between them.

In Fig. 31 statistical analysis was done. There was a linear increase as bigger was the weight. The R^2 was 0.97, i.e. it was almost a perfect linear equation. This means that %MVE and weight are linearly correlated and are practically directly proportional. Also, the slope was stronger reaching bigger %MVE values faster as the load increase and when the loads are lighter, the slope increased in a flatter way. This result is similar as the one done with *hand grip* method in [9].

Because of these reasons there were some **strengths** on this project. One of them was that Movesense sensor could be feasible for comparing some measurements and normalizing the EMG signal. This method could be a cheaper and a useful way for practitioners or for doing measurements in an occupational sector what would mean that one of the aims of the project was achieved. Another was that the Movesense Showcase App was easy to use and it was observed directly on the screen how the signal was being written, nevertheless, there were no measurement units available on the app screen.

Other benefits of the sensor were having a large duration of battery and being connected by BLE. The Movesense Showcase App was available for all phones but there was some difficulties with the android app because for having it you should download and install an .apk, i.e. it was not on PlayStore, while in iOS it was available on the AppStore. The app on iOS was also easier, had a better interface with the user and a better usability with files generated.

Some of the **limitations** of the project were that the number of participants was reduced and measurements were obtained in a house with postures during the MVCs activations and the efforts with loads. Also, it would be better to create a better structure for fitting the electrodes and the sensor than one with wires as shown in figure 13.

Another drawback was that processing the data needed coding knowledge about MATLAB, in this case, for programming the code and analysing the files obtained. Also, reading .csv files on MATLAB was the first problem faced.

Despite the disadvantages, the newness of having a wearable sensor that could measure not only ECG, but also EMG and all the functions that are incorporated on it, and of course, the cost of the sensor shows, that these kind of sensors could drive the society to the better health future for everyone. Additionally, the use of these sensors could lead us to improve the telemedicine.

Finally, verifying the validity comparing the signal with an EMG signal obtained by a commercial EMG was a pending task that was impossible to accomplish due to the difficulties in developing the thesis due to the COVID-19 in the spring of 2020.

5. Conclusion & future works

The use of the Movesense HR+ sensor in combination with a fitted pair of electrodes may be a solution in future use for practitioners, professionals in health and occupational areas. It is an economical and easy to use method. In addition, the *resisted wrist extension* method should be performed for new MVC studies.

In the future, Movesense capability of measuring fatigue would be an interesting issue for following the aim of this study. Regarding limitations, it would be a good project solving all these drawbacks mentioned on Discussion as for example, having a greater number of participants or creating a better structure that easily connected a pair of electrodes with the sensor.

In the future, it should be possible to develop a user-friendly app to make it even easier for the user to interact with the phone so that the professional could perform an easy and good analysis of the signal and its posterior diagnosis. With the development of an EMG app, a “hands-busy” conditions researching could be feasible to be done, a good point of view for the future [11].

Finally, MSDs could be measured and analysed statistically and improving the results obtained by the signal, workdays could be measured in related work tasks as in [31] with an easier way to bring the sensor with the participant. Additionally, with the different functions that the Movesense sensor offers, risk factors on work could be measured on a whole workday. Also, as the battery works by BLE, the consumption is low so measuring during the day would not be a problem. The biggest drawback there would be the connection lost between the mobile device and the sensor.

This method will be able to be used for different occupations and extracted to some health areas as rehabilitation and sports, among others.

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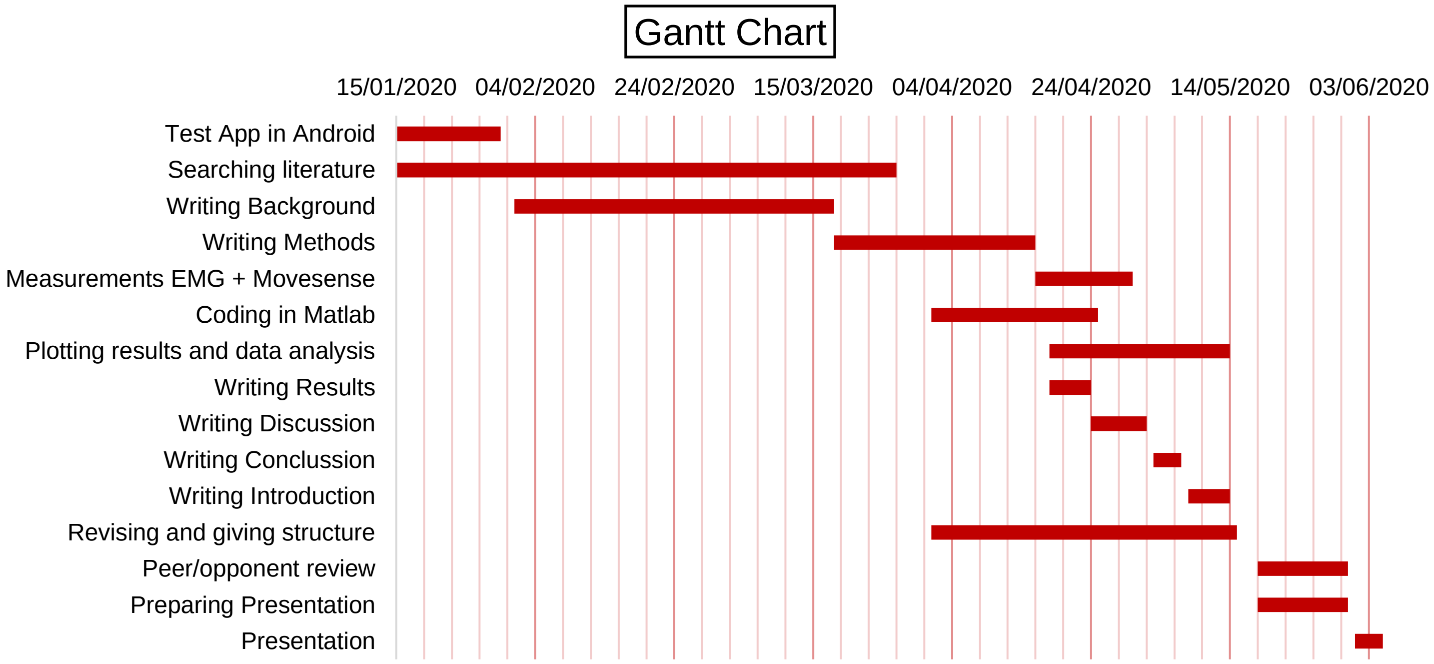
Appendix A


Gantt Chart
15/01/2020
04/02/2020
24/02/2020
15/03/2020
04/04/2020
24/04/2020
14/05/2020
03/06/2020
Test App in Android
Searching literature
Writing Background
Writing Methods
Measurements EMG + Movesense
Coding in Matlab
Plotting results and data analysis
Writing Results
Writing Discussion
Writing Conclussion
Writing Introduction
Revising and giving structure
Peer/opponent review
Preparing Presentation
Presentation