Emanuela Cristina Marcos Teixeira
Licenciada em Ciências da Engenharia Biomédica

Development of a normative base for neurological pathologies based on posturography and electromyography

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Orientador: Prof. Doutora Cláudia Quaresma, Professora Auxiliar, FCT-UNL

Co-orientador: Prof. Doutor Hugo Gamboa, Professor Auxiliar, FCT-UNL

Júri:
Presidente: Prof. Doutor Pedro Manuel Cardoso Vieira, Professor Auxiliar, FCT-UNL
Arguente: Prof. Doutora Sandra Cristina Fernandes Amado, Professora Adjunta, IPLeiria
Vogal: Doutora Cláudia Regina Pereira Quaresma, Professora Auxiliar, FCT-UNL

FACULDADE DE CIÊNCIAS E TECNOLOGIA
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Aos meus pais.

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Abstract

A correct posture is preserved due to the normal recruitment of the muscles by the postural control system. Postural dysfunctions, especially adjustments to the standing position of stroke patients, have been a relevant clinical challenge in the rehabilitation process. These dysfunctions have significant repercussions on the performance of everyday activities.

An evaluation of the postural oscillations in stroke patients allows to elaborate a postural profile, which could be significant on the development of special rehabilitation programs. For this reason, the aim of this study is to identify the postural adjustments in the standing position performed by the stroke patients, combining electromyography and posturography.

To achieve this goal, a protocol was developed in order to create a profile of the postural modifications in the standing position of the healthy subjects, to help at the clinical environment. A group of 43 healthy subjects participated in this work, with ages between 18 and 55 years old, and were performed re-tests for each subject on the day following the first test. Also, a sample of 10 ischemic stroke patients attending the Centro de Medicina e Reabilitação de Alcoitão (CMRA) participated in this study.

Afterwards, some conclusions could be extracted from the results. By analyzing EMG and COP results of both samples, it was concluded subjects studied presented a bigger body sway and higher values of muscle activation in tasks with no visual information. Also, was detected that, in the healthy population, Rectus Abdominis were constantly and similarly activated throughout the all protocol, suggesting their importance in guaranteeing an upright standing position. Finally, in the stroke sample of 10 patients, were noticed higher values of muscular activation, compared to the healthy sample, and a big muscle tone on the right side.

Keywords: Posturography, Electromyography, Posture, Postural Control, Balance, Stroke

Resumo

Uma postura correta é preservada devido ao recrutamento normal dos músculos, pelo sistema de controlo postural. As disfunções posturais, especialmente os ajustes na posição vertical de pé em pacientes com AVC, têm sido um desafio clínico relevante no processo de reabilitação. Essas disfunções têm repercussões significativas no desempenho das atividades diárias.

Uma avaliação das oscilações posturais em pacientes com AVC permite elaborar um perfil postural, que pode ser significativo no desenvolvimento de programas especiais de reabilitação. Por este motivo, o objetivo deste estudo é identificar os ajustes posturais na posição de pé em pacientes com AVC, combinando a eletromiografia e a posturografia.

Para atingir este objetivo, foi utilizado um protocolo responsável por criar um perfil das modificações posturais, em indivíduos saudáveis, de forma a ajudar num contexto clínico. Um grupo de 43 indivíduos saudáveis participou deste trabalho, com idades entre os 18 e os 55 anos, e foram realizados retestes, para cada um, no dia seguinte ao primeiro teste. Além disso, foram feitas recolhas numa amostra de 10 pacientes com AVC, a frequentar o Centro de Medicina e Reabilitação de Alcoitão (CMRA).

Finalmente, algumas conclusões foram retiradas dos resultados obtidos. Ao analisar os resultados da EMG e do COP, de ambas as amostras, concluiu-se que os sujeitos estudados apresentaram uma maior oscilação corporal e maiores valores de ativação muscular nas tarefas sem informação visual. Detetou-se também que, na amostra saudável, os músculos Rectus Abdominis foram constantemente, e de forma semelhante, ativados durante todo o protocolo, sugerindo assim a sua importância em garantir uma posição vertical de pé. Por fim, na amostra de 10 pacientes com AVC, foram observados valores de ativação muscular mais altos, comparativamente à amostra saudável, e um grande tónus muscular no lado direito.

Palavras-Chave: Posturografia, Electromiografia, Postura, Controlo Postural, Equilíbrio, AVC

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Acronyms

CMRA: Centro de Medicina e Reabilitação de Alcoitão
FCT-UNL: Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa
ADL: Activities of daily living
CNS: Central Nervous System
COP: Center of Pressure
COM: Center of mass
BMI: Body max index
MVC: Maximum Voluntary Contraction
RMS: Root Mean Square

Chapter 1

1.Introduction

In this first chapter, a brief explanation about the themes that were focused in this work is made. The introduction is divided into three different parts: motivation, objectives and dissertation structure.

1.1 Motivation

Ensuring an efficient and safe performance of daily activities requires constant adjustments and changes of the body's position. These body modifications depend on the information given by the sensorial, motor and central nervous (CNS) systems [1].

The inability to find a correct posture could trigger complications on a person's balance. This inability is usually associated with many factors such as age or a pathology and it is responsible for disturbing postural control in the basic functions [2].

Stroke is an example of a neurological disease that affects postural stability. It can be caused by ischemia or hemorrhage and can affect the right or left side of the brain. Consequently, this pathology will disturb different neurologic domains, such as the loss of vision, or even the onset of motor disabilities [3].

Brain injuries caused by cerebrovascular diseases are one of the main causes of disability and by the year 2013, Portugal had a mortality rate of 54.6 deaths per 100.000 citizens, directly associated with stroke. Most of the strokes were ischemic and englobed people who were over 65 years old [4], due to the increased risk this disease has with aging.

Thus, patients who survive a stroke normally present some physical and psychological impairments, resulting in a decrease in the ability to perform activities of daily living (ADL). The need to study balance and the postural control in these subjects unveiled some new discoveries, in which it was observed that stroke patients presented a bigger displacement, comparatively to healthy subjects, and an altered weight distribution according to its weaker limb and side [5].

Furthermore, a correct posture is maintained due to that the normal recruitment of the muscles by the postural control system. Considering that the trunk is the body segment with the biggest mass and its role in center of mass changes, namely the dynamic response of the anterior and posterior stabilizing muscles, there is a need to study their muscle activation. Electromyography (EMG) is commonly used in many different postural control studies to access muscle activation [6]. However, it is mostly used to record the lower limb muscle activity. Thus, there is an interest to study the postural control system and the corresponding muscle activation, this time at the trunk level, through the EMG recording technique.

Posturography is another technique widely used in both postural control and balance studies, where is possible to acquire measurements related to the body displacement. It is based on the use of force platforms which allow us to calculate an important parameter, the center of pressure (COP) of each subject [7]. It has also been used as a comparison mechanism which overcomes some disadvantages such as the subjective nature of scoring systems, widely used in clinical contexts (example: Berg Balance Scale) [8,9].

For the reasons stated above, the study of postural control and balance in stroke patients, who present several difficulties sustaining the right posture, becomes of great importance.

For this purpose, this study main goals are to assess the reliability of the healthy subjects' data, by performing tests and retests, to increase a healthy postural database and to identify the postural adjustments of the stroke patients. With the help of a reliable healthy postural profile and after the identification of the postural adjustments in the stroke patients, the development of new rehabilitation plans will be possible, and it may have many applications in a clinical context.

This work is developed in the sequence of a previous master thesis from a graduate student in the Faculdade de Ciências e Tecnologia da Universidade Nova de Lisboa (FCT-UNL), Ana Rita Mendes, who used EMG and posturography simultaneously, to collect data in patients with rheumatologic pathologies [10]. In her study, a protocol was developed, and a normative base was elaborated with a group of 35 healthy subjects and 10 rheumatologic patients.

In this project, the previously developed protocol was used, in a sample of 43 healthy subjects and retests were made with a time distance of 24 hours from the first day, in all the subjects. This procedure would help to validate the results and test the reliability of the healthy data.

A sample of 10 stroke patients was added to this work to understand their postural adjustments and compare them to the healthy sample. These patients performed 5 of the 9 tasks of the referred protocol, due to the difficulties felt executing some of the other tasks. A second test was performed, according to these patient's availability, so that a comparison was made between both results.

Healthy subject's acquisitions were performed in FCT-UNL and, after the approval from the ethics committee of the Centro de Medicina e Reabilitação de Alcoitão (CMRA), stroke patients' acquisitions were in CMRA.

1.2 Objectives

For the rehabilitation process of stroke patients, it is important to compare their posture and balance dynamics with a healthy postural profile. For this reason, the main goals of this study are to increase a previous database of healthy subjects, to investigate the reliability of the test's results and to identify the postural adjustments. Additionally, to achieve these objectives it is important to:

- Validate the protocol in a laboratory context by performing test and retest, for each healthy subject; Analyze the test and retest results;
- Validate the protocol in a clinical context by performing test and retest, for each stroke patient; Analyze the potential differences in the results;
- Analyze the biomechanical and electrophysiological parameters of the healthy subjects;
- Develop a healthy postural profile; Augment the previous healthy normative database;
- Analyze the biomechanical and electrophysiological parameters of the stroke patients.

1.3 Dissertation Structure

The present project is composed of five chapters, in which the theoretical fundaments, the methodology of the study, the results and discussion are presented. The document is structured as follows:

- Chapter 2 - Basic concepts of postural control and balance explanation as well as muscle activation, electromyography and posturography;
- Chapter 3 – State-of-the-art;
- Chapter 4 - Materials and Methodology;
- Chapter 5 - Main results;
- Chapter 6 – Discussion;
- Chapter 7 – Conclusions and future work.

Chapter 2

2. Theoretical Background

In this chapter, some important theoretical concepts will be introduced, in order to understand the basis of the work. Themes like postural control system and balance, issues affecting postural control and what is used to evaluate posture and postural control, will be described.

2.1 Postural Control System and Balance

On a day-to-day basis, the ability to control posture and maintain balance is important to the independence of each individual, being a field of study with increasingly interest in the rehabilitation area [11]. A functional postural control is responsible for the coordination of all the body segments and if the center of mass (COM) is within the limits of the support base, body balance is guaranteed and it allows the performance of any activity or movement [12,13].

A correct posture is defined by the condition of balance between bones and muscles, and the relative alignments of the body elements, which enables the accomplishment of any action or just the sustenance of the body and it is a very important body ability [7,14]. Body posture can be characterized as static, when the human body remains in balance during quiet standing position, or dynamic, when the body remains in equilibrium during any movement [7]. Both have different behaviors and will be important for this work.

In order to control all body elements and preserve an upright standing position, a postural control system is necessary. A healthy postural control system uses the information given by the sensory, motor and central nervous systems [2,15] and has two essential functions - maintaining equilibrium and postural orientation. Postural orientation relates the alignments of the body segments with gravity and the surrounding environment. Postural equilibrium is the sum of all body forces applied to stabilize the COM, when in stability disruptions [2].

Sensory information, from the somatosensory, vestibular and visual system, is used by the brain to create a mental position of each body segment, in relation to the environment. The central nervous system (CNS) uses this information to send nerve stimuli to the motor system, responsible for the muscles responses. These responses guarantee stability and all the body displacements in order to perform any daily activity [2,14]. Study these systems' influence and their responses is important to the analysis of balance disorders and might help to predict possible risks involved [15].

One of the most important group of muscles, crucial for the human body ability to execute different postures, are the trunk muscles. They are responsible for preserving stability in daily activities, which makes them very relevant for this study [15].

Trunk stability is promoted by a coactivation of two distinct groups of muscles. First, there are the global muscles, such as the Rectus Abdominis and the External Obliques, responsible for the trunk movement and for transferring the resulting force to the lumbar spine. Local muscles, like the Transverse Abdominis and Lumbar Multifidus, have a direct attachment to the vertebrae and they are used to control curvature and the stability of the lumbar spine. Both local and global muscles have a significant role during all the body adjustments [16,17]. In this work, Rectus Abdominis, External Obliques, Lumbar Multifidus, and Iliocostalis will be studied during a protocol of nine tasks, with different body postures.

There are different physiological systems responsible for the postural control that might be disturbed by pathologies or health condition. When one or more systems suffer some disturbance and stop working correctly, unwanted situations might occur [15]. Thus, posture can be influenced and disturbed by several factors, such as, aging, some pathologies or disorders in the postural control system, body mass index (BMI) or even the practice of physical exercise.

2.2 Factors that disturb postural control

- **Aging and postural control**

After the age of fifty, population in general suffers from equilibrium problems, influencing the ability of a person to maintain a correct postural balance, when performing any movement with one or more body segments, or responding to any external disturbance. This inability to maintain the balance might be caused by the deterioration of the systems responsible for postural control, associated with aging [18].

Modifications in visual, vestibular and somatosensory functions, deficits in sensorimotor processing and in the musculoskeletal integrity happen regularly with aging. Older people have also a high probability to develop pathologies affecting the central nervous systems, which could cause modifications in the postural control management.

It is known that, when compared with a younger group of people, an individual with more than fifty years of age has longer postural responses to the external and unexpected perturbations, and their muscular weakness increases. For these same reasons, older people feel more difficulties performing the daily tasks autonomously [19,20].

Besides all these modifications, there is a loss in the depth perception and in the visual acuity, associated with body unbalance, falls and serious injuries, very common in older ages, and causing poor quality of life [21].

- **Body mass index (BMI) and physical activity**

Body mass index (BMI) or Quetelet index is used to evaluate the total amount of body fat and relates the weight and the height of the subject (expressed in kg/m^2). This measure is normally known as an obesity and overweight indicator. According to the subject's body fat, a higher BMI value might cause some negative effects on postural control [22].

Deforche et al. [23] concluded that overweight impairs children's ability to control static and dynamic postures, but there are no studies that directly relate to BMI and postural control, only excessive weight increases the difficulties in maintaining and controlling a stable posture [24].

Physical activity is described as any movement of the body with associated loss of energy expenditure. It has been observed that it improves health effectively and prevents instability situations, especially for older individuals [25]. It is known that the practice of physical exercise improves muscle strength and endurance, increases bone density and functional ability. Thus, it is a good habit to prevent potential injuries and falls, at any age [26].

- **Disorders in postural control system**

The body's ability to adjust posture, according to whatever the stimulus or disturbance, is a responsibility of the postural control system. This system relies on the CNS, on motor system and sensory system for executing all the modifications quickly and efficiently. If there is a failure to coordinate the muscles and joints movements or some disturbance in any of these systems, stability is at risk [15,19].

For the body to remain in balance, it is necessary to consider both the size and the quality of the support base, in this case, the feet, as the COM control. Stability limit is the area within which the COM can be moved without disturbing the equilibrium. This area has the shape of a cone (see figure 2.1) [15].

Figure 2. 1 - Representation of stability limits (Adapted from [15])

Additionally, if the ability to stand or to perform any daily activity depends on a complex interaction of the systems responsible for postural control, there is a need to be evaluated these systems to understand what is incorrect with a person's balance [15,19].

The sensory system can be divided into three, the visual system, the somatosensory and vestibular systems. There is not a system more important than the other, but it is thought that the body remains oriented and balanced with the correlation of the information provided by these three systems [27].

From the visual images obtained by the eyes, important information is sent to the CNS by the visual system. With that information, the human body can adjust is movements as required. However, there are some visual disorders that could affect the ability to position the body with respect to the visual surround, such as visual agnosia - deficiency in which the individual is not sensitive to three-dimensionality. Although there may be some visual limitations, the CNS can use other information provided by the sensory system, thus balancing some visual limitations [28].

Patients with some vestibular disorder reveal an increased postural instability. One of the inner ear elements essential for maintaining balance is the bony labyrinth. Some disorders related to this system are sensed in patients, as is the case with dizziness which, when having a rotating character, is called vertigo. Implicit to dizziness and vertigo are nausea and loss of stability. These symptoms will cause disorder, postural sway and consequently will decrease the quality of life [28,29].

Somatosensory system acquired information through his receptors spread all over the body and can be divided into: temperature, touch, position, and pain. After receiving all the stimuli, the CNS analyzes and generates responses accordingly. In the case of the lack of information and if CNS fails at the reception and doesn't communicate to the motor system, there will be potential falls or imbalance situations, highly associated to neurological diseases [30,31].

Some of the pathologies associated with postural control changes are Parkinson disease, stroke or even multiple sclerosis (MS). MS is an inflammatory and demyelinating disease, in which there is damage of the myelin sheath that surrounds the axons of the neurons. Neurological damage increases in the course of the disease and communication problems occur between the brain and the rest of the body. The most frequent lesions in individuals with this pathology are ataxia - gait disturbance -, coordination troubles and issues with balance and posture [30,31].

Stroke is another neurological pathology known as the loss of brain function, due to a disruption in blood supply in CNS, which can cause several complications. These complications will be explained below.

- **Stroke and postural control**

As previously indicated, a stroke is defined as a loss of brain function resulting from a disruption in blood supply to the CNS. It is a serious neurological disease and represents one of the leading causes of death and disability [32,33]. Brain functions are damaged by the injuries motivated due to an ischemic stroke – irrigation failure of the blood due to the obstruction of a vessel - or a hemorrhagic stroke - when a vascular rupture and blood loss occurs. Consequently, motor disturbances will follow, such as complete or partial paralysis [34].

Clinically, both in ischemia and in hemorrhage, it is frequent to observe individuals with hemiplegia and hemiparesis. Hemiplegia is the paralysis of the side of the body contrary to the side of the brain injury, and other associated symptoms can be observed such as language disturbance or decreased sensitivity. Subjects with hemiparesis frequently demonstrate muscle weakness, spasticity, and deficits in movement coordination. In addition, it is important to detect and correctly analyze the lesion's location in order to better classify and understand the accident's nature [34].

A decrease of superficial sensibility produces some changes and perturbances of the body image and a reduction in proprioception sensitivity – responsible for ensuring postural balance – affects the ability to execute controlled actions sensitive to the position and movement, in such a way that it incapacitates, once again, the correct postural control [34].

In patients with a stroke diagnosis, some issues can be verified in the perceptual function, such as apraxia and agnosia. Apraxia is a disability to program sequences of movements and can be demonstrated in gestures or tasks. Individuals with agnosia are unable to identify and give function to familiar objects. It leads to some very common disorders associated with communication, which is the case of aphasia, characterized by the existence of disturbances in language [34].

Finally, stroke patients generally reveal alterations in the muscle tone, and the presence of spasticity patterns and different postural characteristics are noticed, such as irregular postures and movements. These will cause great difficulties in performing functional activities like sitting, standing, walking and performing any daily movement [34].

Considering the complications felt by these patients in postural control, it is intended to identify the postural adjustments in stroke patients and compare their results with a healthy postural profile.

2.3 Techniques used to evaluate posture and postural control

2.3.1 Electromyography (EMG)

Muscles have specialized cells which generate forces and movements responsible for the contractions necessary to guarantee stabilization and the correct performance of all body postures required [35].

Considering that the trunk movements are necessary to maintain postural control and the right recruitment of the trunk muscles is essential to preserve stability during the performance of any daily activity, there is a need to study their muscle activation [15,16].

In order to measure and evaluate the trunk muscles' activation, more specifically the Rectus Abdominis, the External Obliques, the Iliocostalis, and the Multifidus, a technique known as EMG is used. Surface electromyography is known as a powerful non-invasive technique to evaluate the healthy and the pathological patients' electric signals, measured by EMG sensors. These signals are studied in the muscle and are produced by the physiological variations occurring in the muscle fiber membranes [36-38].

Initially it is important to understand that the functional unit of the neuromuscular system is the motor unit, which is constituted by the motor neuron, its dendrites, the axon and the muscle fibers that are innervated. Motor neuron generates an action potential and consequently, in all the muscle fibers, belonging to the motor unit, action potentials are produced and the EMG signal is recorded in the muscle [36,39,40].

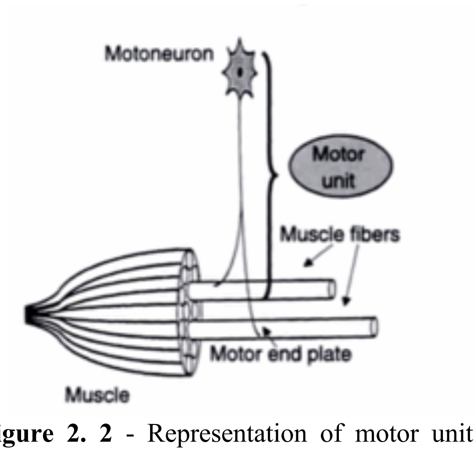


Figure 2. 2 - Representation of motor unit (Adapted from [41]).

The muscle fibers are unnerved by a single motor neuron and they're excitable through a phenomenon, which is explained by the semi-permeable characteristic of the membrane [36, 39].

The muscle is relaxed, and no contraction occurs when there is ionic difference between the inner and outer spaces of the muscle cell of approximately -80 to -90mV. This ionic difference is called resting potential and is guaranteed by the ion pump. When the muscles fibers are excited, the ion pump opens and Na^+ ions flow in. A positive intracellular potential occurs, and it is responsible for the membrane depolarization [36, 39].

Right after, the restitution of the ions' levels by backward exchange, using the same mechanism, is known as repolarization [36, 39].

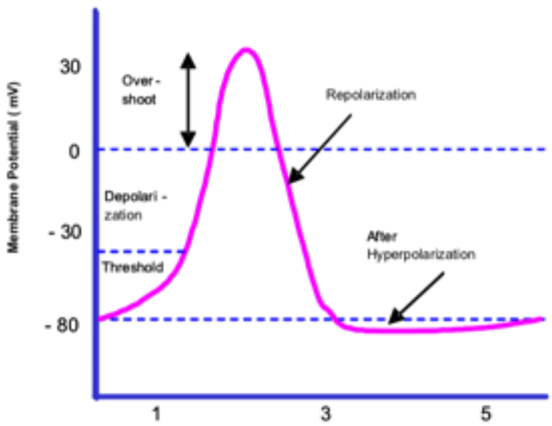


Figure 2. 3 - Representation of the action potential (Adapted from [36]).

In depolarization, when a threshold is exceeded, the values change from -80mV to +30mV and an action potential is produced that is spread along the muscle fiber, in both directions. EMG sensors are placed on the surface of the skin and will detect the sum of all action potentials [36][40].

The recorded signal can be influenced by the anatomical and physiological characteristics of the muscles, and it might be affected by many external factors [35, 36]:

- **Tissue characteristics**

The human body is a good electric conductor, but this good conductivity varies from individual to individual, and according to the tissue, its thickness, any physiological modification, and temperature. However, there are some factors that may also change the recorded signal like the amount of tissue between the muscle's surface and the electrode, the existence of fat mass - that it is a bad conductor tissue -

, deepness and location of the active fibers and the orientation of the detection surfaces, in relation to the muscle fibers [35, 36].

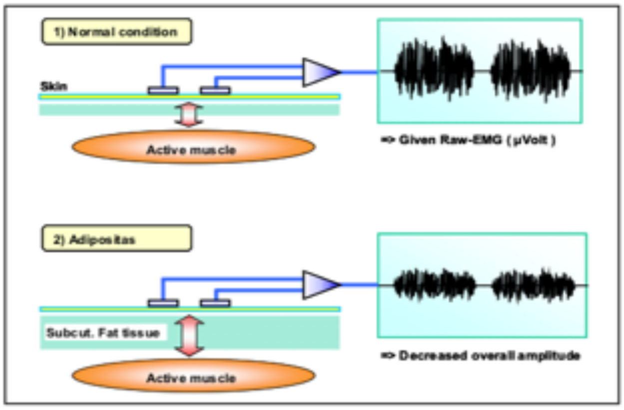


Figure 2. 4 - Representation of different EMG signals due to the presence of a fat mass layer, that increases the distance between the electrode and the active muscle (Adapted from [36]).

- **External noise**

Electronic devices and the incorrect positioning of the ground electrode can influence the detected signal. The place where the electrodes are positioned and their distance from the muscles being studied is important, since what is intended is to minimize crosstalk and the signal distortion. Thus, it is essential to take special attention to the positioning of these electrodes when acquiring data [36, 41].

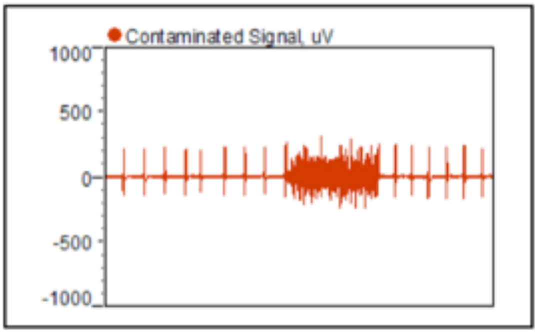


Figure 2. 5 - Exemplification of EMG record with the interference of electrocardiogram (ECG) (Adapted from [36]).

- **Electrodes**

The signal can be affected by several aspects regarding the format and quality of the electrodes used. The placement of the electrodes is very important so that they are positioned right, in order to acquire the signal of the muscle being studied and so that it doesn't disconnect easily [35, 36].

In order to analyze EMG data, there are some parameters that were considered to be important when studying muscles activation, such as the mean and median frequencies. Using the Fast Fourier Transformations algorithm, it is possible to create a frequency distribution graphic so that these mentioned frequencies could be explored and provide essential information [36].

It is known that the maximum value of the total power spectrum represents the peak frequency. Total power parameter is calculated by the integral under the spectrum curve and it allows the calculation of the mean and median frequencies. Median frequency is obtained by dividing the total power area into two equal parts and the mean frequency is produced by these spectrum curve's mean [36].

2.3.2 Posturography

This technique is based on the use of force platforms, which evaluate posture and balance, and allows the calculation of the center of pressure (COP) of each individual. It is known for being a safe method to assess balance, widely used in a clinical environment for the detection of musculoskeletal disorders [42].

Posturography is divided into static and dynamic posturography. The static posturography, postural control is assessed in positions were the subject's body is not in much movement. In the dynamic posturography, individual's responses are studied when disturbances are imposed [7]. In this work, static posturography will be used.

From the measured coordinates acquired by the force platform, during the all protocol, COP will be calculated. This parameter is, by definition, the application point of the resulting vertical forces performed by the body, in order to maintain its equilibrium, on the platform. In this way, the data that is analyzed directly is the trajectory of the COP into two different directions – anterior-posterior (AP), known as y direction, and medial-lateral (ML), often referred as x direction. [7].

Considering that the force platform is the most common technique in postural evaluations, and that the COP is the most commonly used parameter [43], there are certain measurements to be focused on, such as the amplitude, the standard deviation and the total area of COP trajectory (see figure 2.6), COP frequencies and mean velocity.

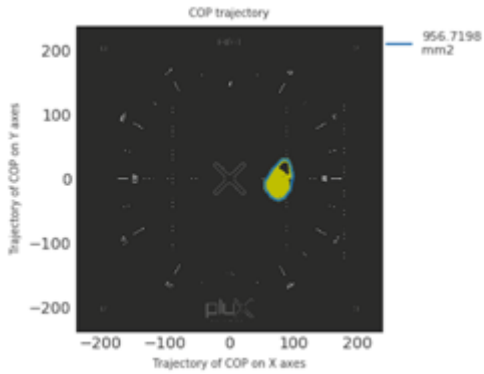


Figure 2. 6 - Illustration of force platform where is represented the total area displacement (marked with the blue line) and COP trajectory (marked with the yellow lines).

The terms COP and center of gravity (COG) are often confused, but they represent two different concepts. Although the COG can't be measured directly, using the data acquired by the force platform, the COP and the COG are two variables widely used to study the postural control system. Alterations due to an external stimulus can make the COG pass the stability limits, causing a change in the forces applied on the platform. Consequently, a bigger displacement of the COP will be displayed [7,43].

Chapter 3

3. State-of-the-art

In this chapter, the use of two different techniques, EMG and posturography, in postural control studies, will be presented. It is essential to know what has already been done in the past, so that these studies can bring something new to science and to postural control assessments.

3.1 Posturography

The need to understand clinical studies relative to balance has been growing, not only at the level of medical diagnosis but also at the therapeutic level. Initially, in 1968, tests were performed to assess the ability to maintain balanced. In 1992, Berg created a balance scale that it is still used today, but one of its disadvantages is the poor sensitivity [44].

Since all the rating scales used were clinically subjective, there was a need to develop an objective assessment method with quantitative measurements. Considering these clinical difficulties, a force platform was developed, with the purpose of evaluate the nature of the motor coordination problems [44]. Through this system, it is possible to measure the COP and other relevant information is collected for the evaluation of the postural control system. It was in the sense of overcoming some limitations that several protocols were studied for the acquisition of relevant and useful data [45].

Benvenuti [46] created a protocol that uses the static upright standing position to quantify the nature and severity of the postural instability of each individual. Eight tasks were performed in this protocol:

1. Standing position with eyes open, large base and firm surface;
2. Standing position with eyes closed, large base and firm surface;
3. Standing position with eyes open, large base and silicone surface;
4. Standing position with eyes closed, large base and silicone surface;
5. Standing position with eyes open, a narrow base and firm surface;
6. Standing position with eyes closed a narrow base and firm surface;
7. Standing position with eyes open, a narrow base and silicone surface;
8. Standing position with eyes closed, a narrow base and silicone surface.

After the study was completed, it was found that this protocol might not be challenging enough to reveal that changes in postural control would arise with age [46].

Nashner [18] developed the Sensory Organization Test (SOT), which is composed of six sensory conditions that evaluate the individual's balance. In this test, two force platforms and a mobile screen - EquiTest System- were used, a system also used in the Ford-Smith study (see figure 3.1). Differences in the body displacement were verified due to the diverse sensorial conditions, conditioning the individual's ability to organize and to choose the appropriate sensory information for the body to remain balanced.

Finally, it was concluded that the SOT protocol was useful in detecting instability in older individuals and thus, valuable to prevent potential falls [18].

Figure 3. 1 - Patient using EquiTest System (Adapted from [19]).

Regarding the comparison between younger individuals and older subjects, both without pathology, Sabchuk et al. [47] found that the tests on the force platform made possible to distinguish between these two age groups. They observed that amplitudes did not vary from one group to the other, in the AP direction and in the two conditions of separate feet and feet together, both with open eyes. However, COP velocity was correlated with age, for the separate feet and eyes open condition.

There were some differences between the two groups in the eyes closed condition, so it can be said that, in the elderly, a greater postural control is required when reducing sensory information [47].

Lastly, Dault et al. [48], noticed in their study that young healthy subjects presented reduced amplitudes and increased frequencies in the sagittal and frontal planes, with visual feedback. Concerning the COP velocity, only a minimal increase was observed. However, these results were not observed the same way for the elderly subjects, who presented more difficulties in controlling the body sway. They also realized that healthy elderly subjects and stroke patients revealed a higher imbalance, with COP velocities and amplitudes higher than the younger subjects, especially in the sagittal plane.

Regarding the studies performed on stroke patients, Messier [45] studied and quantified trunk movements, in these patients with hemiparesis, and compared their results with data from a group of healthy individuals. The subjects were seated in a chair placed on a force platform and the feet would also set upon two platforms. Thus, force values applied on the buttocks and on each foot were measured. A lower displacement of COP in individuals with hemiparesis was found which suggested a lower shift of center of mass, during trunk flexion.

In 2004, Corriveau [49] compared balance measurements of the elderly stroke patients with the healthy elderly individuals. He verified that COP amplitude was larger for the stroke patient's sample with eyes open and eyes closed. Comparing both conditions, it was larger with the eyes closed than with the eyes open, supporting the idea that patients would first rely on the visual information.

Still concerning the postural control in stroke patients, Bonan [50] also observed that patients with hemiplegia seemed to rely on visual input. He used computerized dynamic posturography (EquiTest) to evaluate stroke patients and their inability to use information from postural control system. It was concluded that clinic rehabilitation should include some exercises to be executed under the conditions of sensory input deprivation and sensory conflict.

After these conclusions, other Bonan [51] study came to show that a balance improvement occurred after rehabilitation with visual deprivation, in patients with hemiplegia.

3.2 Electromyography

This technique began to be developed in 1666 by Francesco Redi's and by the year 1773, it was shown that the muscles tissues of the eel fish produced electricity. It was only in 1792 that Galvani proved that electricity could cause muscular contractions [35].

However, it was in 1849 that the possibility of recording electrical activity during a voluntary contraction was discovered. This recording occurred in 1890, by Raez et al. [35], who was also responsible for the introduction of the term electromyography.

Subsequently, great progress was made in the detection of the signals and in the electrodes used. In 1960, EMG began to be used in the most diverse areas and in the study of specific diseases, such as in the analysis and diagnosis of neurological and neuromuscular diseases. It can be used in various sciences as in psychology, biomechanics, neurology, physiotherapy and in the study of postural control [35]. Basmajian and De Luca [41] also had an important influence in this matter. They had written a book with all the previous work, which became known as a reference guide, by the year 1965.

After it was verified that the abdominal muscles had separate actions, Goldman et al. [52] concluded that it was possible to record this activity. Regardless of which muscles were studied, most of the EMG evaluations were qualitative, which made it very difficult to compare studies [53].

One of the most important group of muscles are the trunk muscles. It is thought that these muscles provide an important contribution to the stability of the spine and, for this reason, different studies using EMG have been developed in the trunk area, associated with the evaluation of postural control [15,54].

For this reason, O'Sullivan et al [54] demonstrated that the Internal Obliques and the Superficial Lumbar Multifidus revealed greater muscular activation in subjects without low back pain. The postures used in this work, like the standing and sitting postures, were frequently observed and were considered reliable, quantifiable and efficient in a clinical context.

According to Hodges et al. [6] the Transverse Abdominis (TrA), require more investigation. In this study, low back pain patients were also analyzed, and it was detected that the pain produced differential changes in the motor control of the trunk muscles, especially in the TrA.

Some studies evaluated the activity of the trunk muscles after a stroke, using EMG, such as the work of Marcucci [55]. In his study, the activation values of the Rectus Abdominis were compared between a control sample and stroke sample. It was observed higher values for the muscles on the side of the hemiparesis, for a specific task of stabilizing the pelvis.

In a previously developed work for rheumatologic diseases, EMG and posturography were used simultaneously in order to perform tests in the healthy subjects and in the pathologic patients. It was concluded that the Rectus Abdominis had an important role in maintaining an upright standing position and bigger displacement of the COP was detected for the tasks with no visual information. Both populations presented similar results performing the same protocol [10].

Chapter 4

4. Methods and Materials

The present chapter makes a short introduction of the equipment used in the study and the two questionnaires developed for each sample are presented. Additionally, the protocol used in this work and the data analysis processing are described.

4.1 Equipment and Questionnaire

At the beginning of all acquisitions, the subjects had to read and sign an informed consent and fill out a questionnaire.

Two separate questionnaires were made, and an informed consent was developed, one for the group of healthy individuals and another for the sample of stroke patients. The aim of the questionnaires was to collect information about the subjects that could have a significant influence in postural control. The relevant information collected in the healthy subjects was:

- Socio-demographic characteristics: nationality, profession, academic qualifications, marital status, and gender;
- The biomechanical characteristics: age, height, and weight;
- The subject's dominant hand.

Regarding the stroke patients, the important information gathered was:

- Socio-demographic characteristics: nationality, profession, academic qualifications, marital status, and gender;
- The biomechanical characteristics: age, height, and weight;
- The clinical diagnosis and the muscle spasticity;
- The patient's dominant hand.

The questionnaire and the informed consent addressed to the healthy individuals can be consulted in appendix A. The second questionnaire and the informed consent carried out for stroke patients can be consulted in appendix B.

After the approval of these documents by the ethics committee of the Centro de Medicina e Reabilitação de Alcoitão (CMRA) data was recorded in the healthy subjects and stroke patients. The equipment used for the acquisitions were a force platform and an EMG acquisition system.

The force platform chosen was from Plux* and is composed of 4 steel load cells and can support up to 800Kg (200kg per cell). In addition, it is capable of sending all data via Bluetooth to a sampling rate up to 1000Hz and a 16-bit resolution [56]. (Figure 4.1a))

For EMG, Biosignals research kit, also from Plux*, was used, formed by 8 analog channels with a resolution of 16 bits. The data was sent via Bluetooth, with a sampling rate of 1000Hz [56] (Figure 4.1 b)).

a) b)

Figure 4. 1 - Equipment used. a) Force platform and b) Biosignals research kit (Adapted from [56]).

Eight EMG sensors named emgPLUX and disposable electrodes were used for all the tests. Afterwards, the data was stored in H5 files and processed using a code in Python language. This code was developed for this specific study and pathology.

4.2 Protocol

Measurements in two different groups were made in two moments – tests and retests - and the same protocol applied to the healthy subjects and to the stroke patients.

- **Test-retest**

In this study, all the healthy subjects were submitted to tests and, one day later, executed the same protocol – retest. This process gave the necessary data to compare both tests and analyze the reliability of the tests results. Thus, it was possible to understand if the healthy data is valid to be used in a medical context. As mentioned in [57]: "Clearly, if data are to be used to evaluate, train, and monitor changes in balance performance, test-retest reliability and validity of the data are fundamental. Further, test-retest reliability in individuals with impaired balance cannot be inferred from studies involving healthy control populations".

*Plux Wireless Biosignals SA, Portugal

Therefore, stroke patients were tested and submitted to these evaluations twice, in order to understand if there were any changes in the results, attending to these patients' impairments. The second tests performed were one, two, five, six and seven days after the first one, according to the patient's availability.

- **Healthy Subjects' test**

EMG signals were recorded from four different muscles and, to prevent noise in the electrical signal, a ground electrode was placed in the pisiform bone [10]. The evaluated muscles were:

- The Rectus Abdominis (around 3 cm lateral to the midline above the umbilicus) [10];

- The External Obliques (around 10 cm lateral to the midline above the umbilicus and aligned with muscle fibers) [10];

- The Iliocostalis (around 6 cm lateral to the midline at the L3) [10];

- The Multifidus (around 2 cm lateral to the midline at the L5) [10].

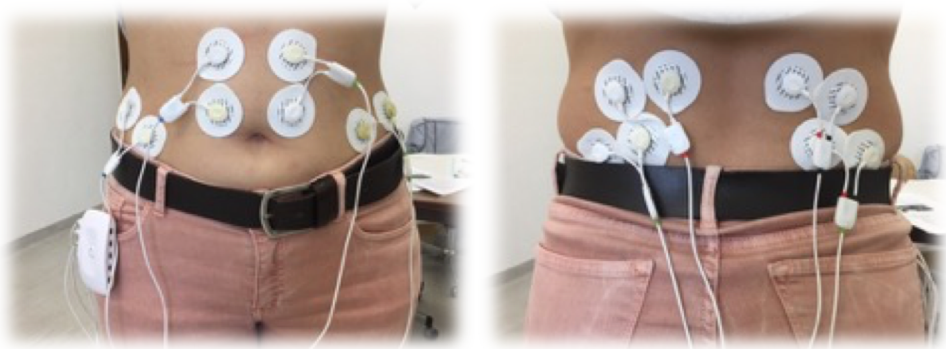


Figure 4. 2 – Displacement of the electrodes in the studied muscles.

First, the subject was asked to lie down on a marquise for 15 seconds in the supine position, in order to record a baseline for the muscle activity.

Since the amplitude of EMG signals can be influenced due to various conditions, such as the electrodes used or even the subject submitted to the study, the EMG signals can be normalized using the maximum voluntary contraction (MVC) tests to prevent these problems [36]. Therefore, the MVC tests were performed using the EMG equipment, to record the trunk muscles activity. The subject is then guided to do the following methodology, with each task being repeated three times:

1. For the Rectus Abdominis, the individual placed the clasped hands behind his head, in the supine position. The examiner stood beside the marquise and stabilized the pelvis, leaning across the patient with the forearms and, while

the subject was producing an upright force, the examiner placed his hand on the subject's chest to contradict the movement [58].

2. For the External Obliques, the subject lifted his torso and rotated to one side, while the examiner contradicted this movement by placing his hand on the lifted elbow. This task was repeated for both sides [58].
3. At last, for the posterior trunk muscles, the subject took the prone position with his hands clasped behind his head and performed an upright force, lifting his upper body. The examiner placed his arms across the pelvis to guarantee stabilization and placed one hand between the subject's shoulders, to contradict the movement [58].

Finally, a protocol already developed in [10] was used to acquire data and all the subjects had to perform the 9 tasks on the platform. Concerning the time used for each task: the first 6 tasks all had a duration of 30 seconds each, while for the final 3 tasks (7 to 9), time was counted until the task was completed. [10]

The 9 tasks are described below:

1. The subject stands on the platform in an upright position with his/her hands hanging along the body and with visual feedback (eyes open) [10];
2. The subject stands on the platform in an upright position with his/her hands hanging along the body and with no visual feedback (eyes closed) [10];
3. The subject stands with only the right foot on the ground and with visual feedback [10];
4. The subject stands with only the right foot on the ground and with no visual feedback [10];
5. The subject stands with only the left foot on the ground and with visual feedback [10];
6. The subject stands with only the left foot on the ground and with no visual feedback [10];
7. The subject stands on the platform in an upright position. An object is placed on a table, on the left side of the subject, 15 cm beyond the length of the extended arm. He/she is asked to reach the object with his right hand [10];
8. The subject stands on the platform in an upright position. This time the object is placed on a table, on the right side of the subject, 15 cm beyond the length of the extended arm. He/she is asked to reach the object with his left hand [10];
9. The subject stands on the platform in an upright position and the object is placed on a table, in the direction of his dominant hand, 15 cm beyond the

length of the extended arm. He/she is asked to reach the object with his dominant hand [10].

- **Stroke patients' test**

The MVC tests for the stroke patients were similar, excepting that, in order to measure the posterior trunk muscles' activation. These patients could not lay down in the prone position and execute the last exercise so instead, patients were asked to sit on the marquise and perform a force backward, with is trunk. The examiner placed one hand between the subject's shoulders, in order to contradict the movement.

Also, the nine-task's protocol was reduced to five tasks and are described below:

1. The subject stands on the platform in an upright position with his/her hands hanging along the body and with visual feedback (eyes open) [10];
2. The subject stands on the platform in an upright position with his/her hands hanging along the body and with no visual feedback (eyes closed) [10];
3. The subject stands on the platform in an upright position. An object is placed on a table, on the left side of the subject, 15 cm beyond the length of the extended arm. He/she is asked to reach the object with his/her hand [10];
4. The subject stands on the platform in an upright position and this time the object is placed on a table, on the right side of the subject, 15 cm beyond the length of the extended arm. He/she is asked to reach the object with his/her hand [10];
5. The subject stands on the platform in an upright position and the object is placed on a table, in the direction of the subject's body center, 15 cm beyond the length of the extended arm. He/she is asked to reach the object with his/her hand [10].

To note that, the hand to be used depend on the side of hemiparesis and its ability to move. These data acquisitions were performed at FCT-UNL and at CRMA.

4.3 Data processing

To avoid desynchronization, signals from the EMG sensor and from the platform were recorded at the same time. Signal treatment and data analysis were performed using Python language.

It is important to refer that NumPy toolbox (version – 1.14.2) and SciPy toolbox (version – 1.0.0) were used, in the Python language (version python – 2.7.10).

For platform records, a code in Python language was used and all signals were pre-processed. The raw signal was converted to a COP displacement in the ML direction and AP direction, using the formulas from the datasheet (appendix C). After this process, the signal was averaged out for each direction and some parameters were calculated, such as the amplitude, mean velocity and standard deviation. The Convex Hull algorithm and the Green's Theorem were used to calculate the area of the total trajectory [10].

EMG signals were averaged out and root mean square formula was used to get the signal envelope, using a window of 100 samples – being 1 sample equivalent to 1ms. Each RMS signal was normalized using the maximum value of the MVC tests, so that it could be calculated the mean and median values.

Application of Fourier analysis to the EMG data and to the COP data was done, using a function from SciPy – periodogram -, being possible to calculate peak frequency, mean frequency, median frequency and 80% of the power spectrum [10].

Results were all saved in Excel files, using XlsxWriter (version – 1.0.2) and Openpyxl (version – 2.5.0), and plots were constructed using matplotlib.pylab toolbox (version – 1.10.4).

The boxplots graphics representing the retests results were obtained using Python and a test-retest analysis was made. The paired samples t-Test was applied using the data analysis tools from Excel and all the tables created were saved in the Excel files.

- **Maximum Voluntary Contraction (MVC)**

The amplitude of EMG signals can be influenced due to various conditions such as, the electrodes used or even the subject submitted to the study. In order to prevent these problems, the EMG signals can be normalized using MVC tests [36].

MVC test is performed for each muscle individually and it is necessary to choose some specific exercises to perform the MVC contractions. It is important to ensure that, for that isolated muscle, the maximum force that the subject can do is recorded. Thus, these tests are executed before test trials and against a static resistance [36].

All the MVC values are recorded in one file and then used in the normalization. In this process, the tests trials signals are divided by the MVC values, considered to be the maximum force of that specific muscle [36].

Unfortunately, what must be noted is that the MVC tests could not be the best practice when it comes to working with pathological subjects. Occasionally, the MVC value is not the maximum value that the subject is capable to reach [36].

In this work, MVC tests for normalizing the EMG signals, concerning the posterior trunk muscles of the stroke patients, were different from what was executed for the healthy sample. This it has to be considered as it may influence the final results.

- **Root Mean Square (RMS) Algorithm**

RMS algorithm is frequently used for smoothing the EMG signal and it is based on the square root calculation. This algorithm uses a moving window that calculates the square root of the data inside. After this process, it is created an envelope involving the raw signal [36, 59].
The RMS is calculated by Formula 4.1:

$$\mathrm{RMS} = \left[\frac{1}{\mathrm{N}}\Sigma_1^{\mathrm{N}}\mathrm{f}^2(\mathrm{N})\right]^{\frac{1}{2}} \tag{4.1}$$

The *f* is the signal and the *N* is the length of the window used [60].

It is important to define the window length in which the mean is being calculated and this parameter should be consistent with the purpose of the study. The window length should be longer if the movement is slower however, in faster movements, it is necessary to choose a shorter window. It is known that a value between 50 and 100ms usually work properly in most conditions [36,59].

- **COP signals Algorithms**

In order to calculate the total area of displacement, it is used the Convex Hull algorithm. This algorithm is able to find the smallest polygon that involves a finite set of points. After this process, the value of the area is calculated using the Green's theorem. It is characterized by the calculation of the double integral in a selected region and is used only for limited areas and closed plane figures [10, 61].

Chapter 5

5. Results

The main results of this work will be presented, in the following order: brief description of the statistical analysis used, a brief description of the subjects participating in this study, the analysis of the EMG and COP parameters for a group of healthy subjects, the statistical relation between tests and retests of healthy subjects results, a comparison of each parameter from healthy subjects and from stroke patients, and finally, the statistical relation between tests and retests of stroke patients results.

In order to understand the results that will now be presented, it is important to recognize some important acronyms referring to the tasks performed, and the muscles analyzed.

First, the following acronyms for the muscles:

- **RaR** = Rectus Abdominis Right;
- **RaL** = Rectus Abdominis Left;
- **OR** = External Obliques Right;
- **OL** = External Obliques Left;
- **IR** = Iliocostalis Right;
- **IL** = Iliocostalis Left;
- **MR** = Multifidus Right;
- **ML** = Multifidus Left;

For the tasks, the following acronyms were used:

- **SEO** = Standing with eyes open;
- **SEC** = Standing with eyes closed;
- **RFEO** = One leg stand (right leg), eyes open
- **RFEC** = One leg stand (right leg), eyes closed
- **LFEO** = One leg stand (left leg), eyes open
- **LFEC** = One leg stand (left leg), eyes closed
- **RR** = Reaching an object on the subject's right side, with his left hand;
- **RL** = Reaching an object on the subject's left side, with his right hand;
- **RC** = Reaching an object in front of the subject's dominant hand;

After data acquisition and processing, it was considered that the most important and relevant parameters were mean and median values, the EMG frequencies, COP frequencies, such as frequency at 80% of the power spectrum and mean frequency, total area, amplitude, velocity, and standard deviation.

To guarantee the understanding of the posture adjustments of the healthy subjects and stroke patients, these parameters were statistically analyzed in Python language.

Tests and retests analysis were made in Excel using the statistical test, the paired samples t-Test, for all the parameters. This procedure is very important to understand if the data is valid to be used in a clinical context and to verified if there are any differences between stroke patients' tests.

5.1 Statistical Analysis

In order to analyze a healthy postural profile, to verify the tests results' reliability in a healthy sample and to identify the postural adjustments in the stroke patients, some parameters have to be analyzed with the help of the following statistical tests:

- **The paired samples t-Test –** This parametric test allows us to compare two means from two different and related conditions. Normally it is used to analyze pre-test and post-test, testing if the mean difference between the two samples is significantly different from zero [62]. The null hypothesis is:

  H_0: $\mu 1$ - $\mu 2 = 0$, where $\mu 1$ and $\mu 2$ is the population mean of variable 1 and of the variable 2, respectively

  If the p-values obtained from this test are superior to 0.05, it can be concluded that the difference between the paired population means is 0 [62]. This t-Test was used to compare the results from Test and Retest of the healthy samples and the stroke samples.

- **Wilcoxon Test –** The Wilcoxon test is a non-parametric alternative to the paired samples t-Test and is applied to analyze differences between two conditions, such as pre-test and post-test. The null hypothesis is that the difference between the two samples follows a symmetric distribution around zero [62]. This non-parametric test was used to compare the different tasks for the same muscle or frequency.

- **Mann Whitney Test –** This test is also an alternative to the t-Test for unpaired samples and it is used when there isn't a normal distribution. Its null hypothesis accepts that the two populations have equal distributions [62] and the test was used to compare the two different groups of samples, the healthy and pathological ones.

It is important to refer that the p-values equal and superior to 0.05 were considered to represent a strong correlation. Tables and boxplot graphics were used to expose the data. In the boxplot graphics the representations of the median and mean values are included, so they can be analyzed.

5.2 Sample's characterization – Healthy sample

A total of 43 subjects participated in this study. From these 43 subjects, 19 were men and 24 were women. Before they were submitted to the tests, all the subjects had to fill a questionnaire (see appendix A) in order to enable the characterization of the sample (Table 5.1 and 5.2).

Table 5.1 - Table with the healthy sample's characterization.

HEALTHY SUBJECTS	AGE (YEARS)	WEIGHT (KG)	HEIGHT (M)
MEAN	26.6	64.6	1.69
STANDARD DEVIATION	9.80	12.0	0.094
RANGE	18.0 – 55.0	47.5 - 110	1.54 – 1.87

Table 5.2 - Table with information about the practice of physical exercise.

PHYSICAL EXERCISE	NONE	1-3 DAYS PER WEEK	> 3 DAYS PER WEEK
PERCENTAGE IN A GROUP OF 43 HEALTHY	35%	47%	19%

Among the 43 participants within this study, only 5 had the left hand as the dominant one.

5.3 Analysis of posture parameters - Healthy Subject's Tests

5.3.1 EMG data results

The maximum values could not be used because some were considered to be outliers. During the acquisition, the electrodes often disconnected, causing some interference in the EMG signal and producing unwanted peaks. With that being said, median and mean values were calculated and analyzed since they were considered to be more reliable.

5.3.1.1 Analysis of the Mean and Median Values of the EMG arrays

For each task and each muscle, the mean and median values were calculated (consult appendix D). Both parameters presented outliers that are not considered important, because of the electrode's disconnection.

In the boxplot graphics below (see figure 5.1 and 5.2), the mean values of the Rectus Abdominis and the External Obliques are represented, for the tasks RFEO* and RFEC*. It was verified that both External Obliques have considerably higher values than the remaining muscles and that the activation values of the Rectus Abdominis were similar during all the nine tasks.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

In general, for all the muscles, it was possible to observe higher activation values for the tasks with no visual information.

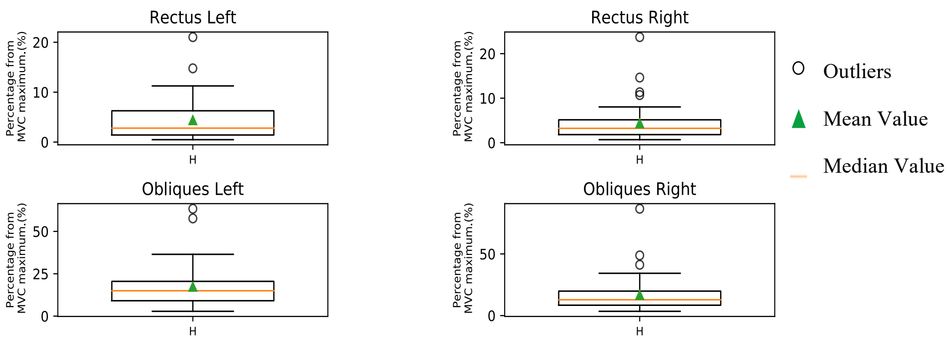


Figure 5. 2 - Mean values of the task RFEO* for Rectus Abdominis and External Obliques, concerning the healthy sample.

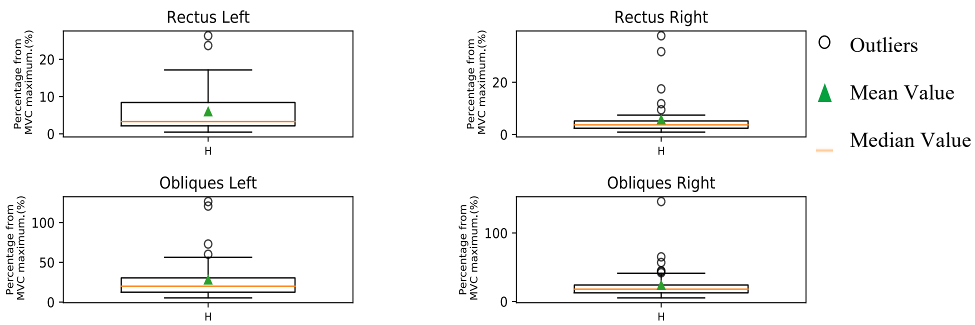


Figure 5. 2 – Mean values of the task RFEC* for Rectus Abdominis and External Obliques, concerning the healthy sample.

Median values were also considered for each muscle and task. Bellow, there is the boxplot graphics for the same tasks referred previously – RFEO* and RFEC* (see figure 5.3 and 5.4). It was evident that the median values were also higher for the External Obliques, especially for the tasks with no visual information.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

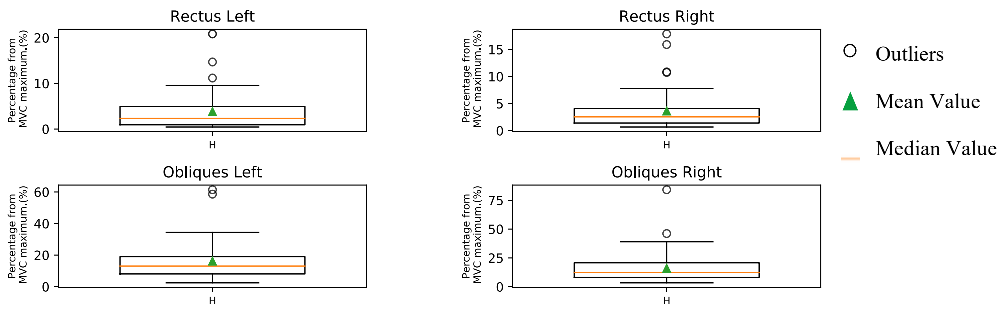


Figure 5. 4 – Median values of the task RFEO* for Rectus Abdominis and External Obliques, concerning the healthy sample.

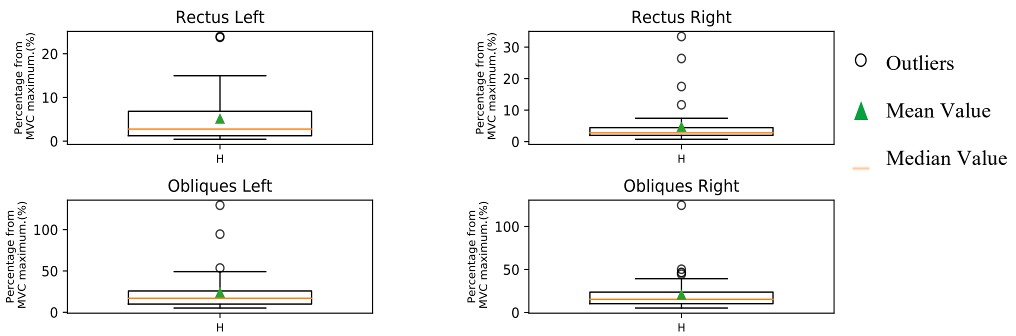


Figure 5. 4 – Median values of the task RFEC* for Rectus Abdominis and External Obliques, concerning the healthy sample.

5.3.1.2 Analysis of the EMG frequencies

Concerning the EMG frequencies, the peak, mean, median and 80% of the power spectrum frequencies were analyzed, for each muscle. All these frequencies are represented in the boxplot graphics (see appendix E). The Wilcoxon Test was used to compare the tasks and p-values higher than 0.05 were considered to represent a strong correlation (see appendix E).

For all the frequencies analyzed, the mean and median values were lower for tasks with eyes closed and for the tasks reaching an object.

The anterior muscles of the trunk, like both External Obliques, presented results with a similar behavior for the range of frequencies considered. A slightly bigger dispersion was observed in the mean and the 80% of power spectrum frequencies, for the left side muscles.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

The Rectus Abdominis were the group of muscles with more similarities between tasks (p-value>0.05), according to the statistical test. Therefore, as an example, in the following boxplots (see figure 5.5 and 5.6) we can observe the peak and median frequencies for Rectus Abdominis left.

Through the nine tasks, it is noticed that the mean and median values, and dispersion, are all similar.

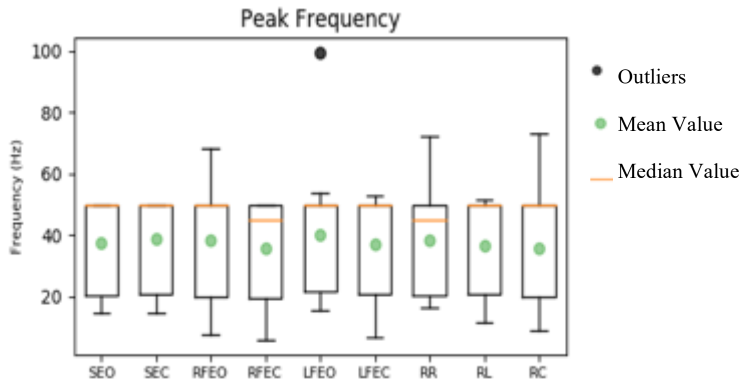


Figure 5. 6 – Boxplot of peak frequency along the nine tasks for Rectus Abdominis left, concerning the healthy sample.

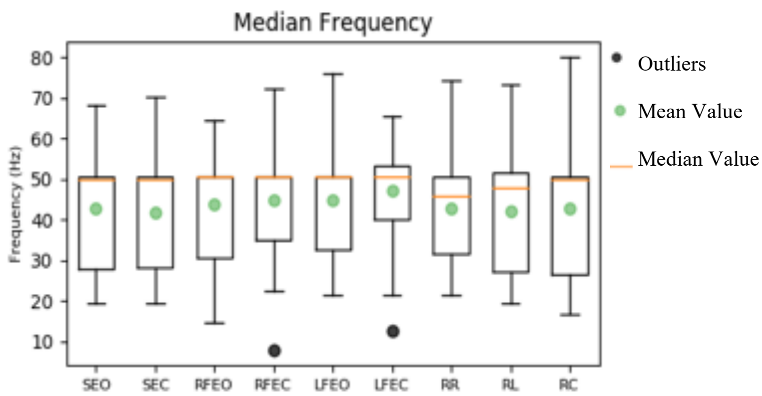


Figure 5. 6 – Boxplot of median frequency along the nine tasks for Rectus Abdominis left, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Regarding the posterior muscles of the trunk, lower values and dispersion were noticed in the tasks with no visual information, along the four frequencies. Of all frequencies studied, bigger dispersions were verified in boxplots representing the 80% of power spectrum frequencies (see figure 5.7).

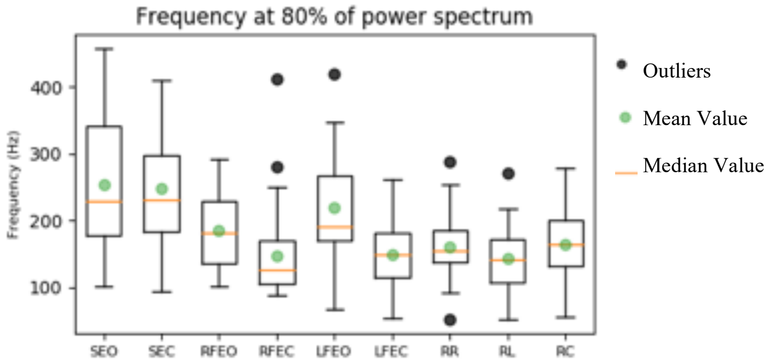


Figure 5. 7 – Boxplot of the 80% of power spectrum frequency along the nine tasks for Multifidus left, concerning the healthy sample.

5.3.2 COP Analysis

5.3.2.1 Analysis of the COP amplitude

COP amplitude was calculated from the data of the posturography tests. For all the 43 subjects the amplitude was analyzed in both directions, x and y. In order to understand the distribution of the data in all the 9 tasks, results are represented in boxplots graphics.

Comparing both directions, x and y, bigger dispersions and a lower number of outliers were observed in the y direction. These bigger dispersions were spotted in tasks without visual information and with only one supporting leg on the platform.

The pairs of tasks such as SEO-SEC*, RFEO-LFEO*, and RFEC-LFEC* present similar values and dispersions among them. The tasks SEO* and SEC* have the lowest dispersion of data and the lowest mean and median values of all tasks, in both directions.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Bigger dispersions were observed in the tasks RFEC*, LFEC*, RR*, RL* and RC*, for both directions (figure 5.8 and 5.9). Higher mean and median values are represented in the boxplots, for the two tasks with no visual information – RFEC* and LFEC*.

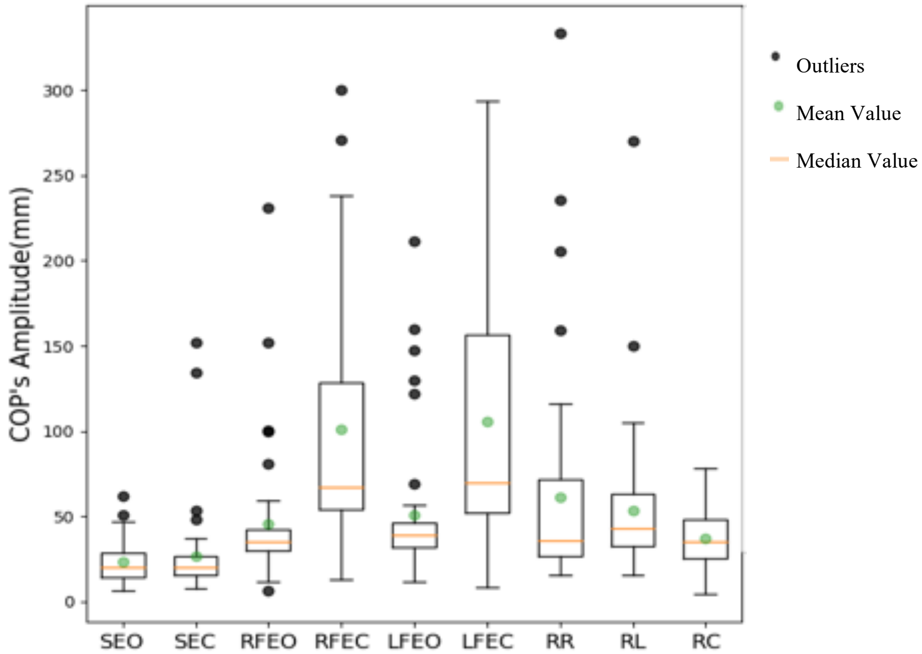


Figure 5. 8 – Boxplot with the representation of COP amplitude in the x direction, concerning the healthy sample.

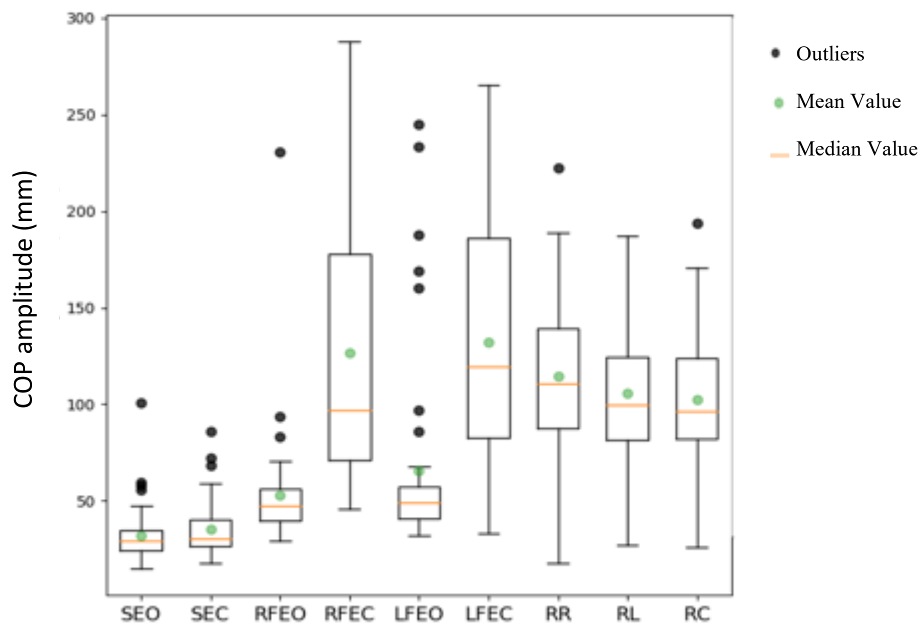


Figure 5. 9 - Boxplot with the representation of COP amplitude in the y direction, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

The Wilcoxon test was used to identify the differences between tasks, and p-values superior to 0.05 were considered to represent a strong relation among them (see appendix F).

In x direction, all the tasks were statistically different (p-value<0.05) with the exception of the SEO-SEC*, RFEO-LEFO*, RFEO-RC*, RFEC-LFEC*, LFEO-RR*, LFEO-RL*, LFEO-RC* and RR-RL*.

In y direction, all the pairs of tasks were statistically different (p-value<0.05) with a few exceptions on the RFEO-LFEO*, RFEO-RR*, RFEO-RC*, RFEC-LFEC*, RFEC-RR* and RFEC-RL*.

5.3.2.2 Analysis of the COP standard deviation

The standard deviations were calculated for both directions. The Wilcoxon Test was applied to compare and analyze the changes between tasks.

In this parameter is used a similar analysis to what was done for the COP amplitude. Boxplot graphics were used, and the mean and median values are represented in these graphics.

Concerning the pairs of tasks SEO-SEC*, RFEO-LFEO* and RFEC-LFEC*, a similar behavior was present between them when analyzing the dispersion, mean and median values. The lower dispersions and values were observed in SEO* and SEC* tasks.

Analyzing the nine tasks in both directions, it can be concluded that the tasks RFEC*, LFEC*, RR*, RL* and RC* present big dispersions, mean and median values (figure 5.10 and 5.11). The SEC* task has the smaller boxplot.

It is important to point out the lower number of outliers in the y direction.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

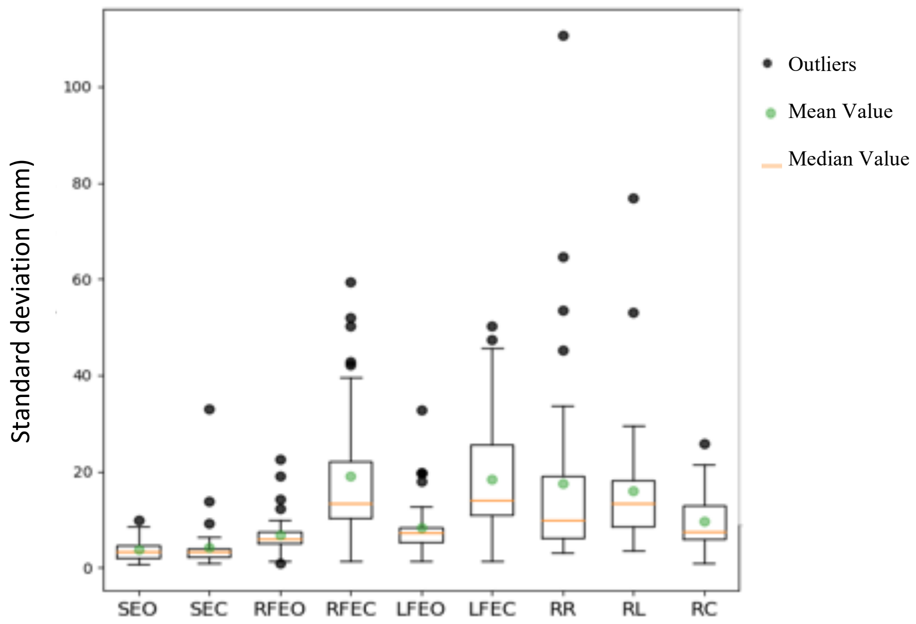


Figure 5. 11 - Boxplot with the representation of standard deviation of COP signals in the x direction, concerning the healthy sample.

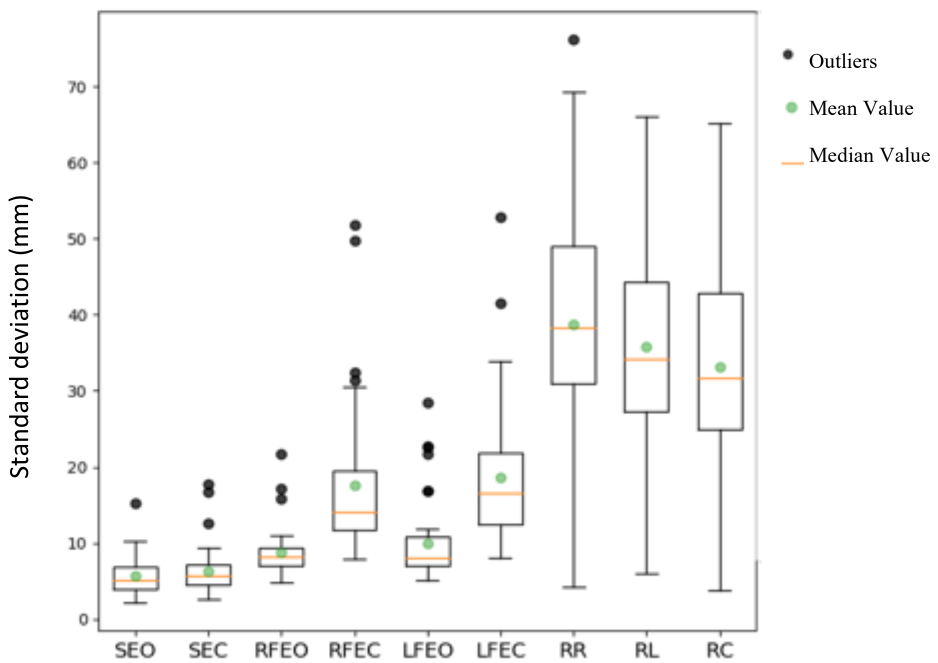


Figure 5. 11 - Boxplot with the representation of standard deviation of COP signals in the y direction, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

When analyzing the p-values from Wilcoxon Test, it was possible to understand that most of the pairs of tasks were statistically different, with the following exceptions for the x direction: SEO-SEC*, RFEC-LFEC*, RFEC-RR*, RFEC-RL*, LFEC-RR* and RR-RL*.

Furthermore, the p-values obtained for the y direction indicated that the pair of tasks SEO-SEC*, RFEO-LFEO*, RFEC-LFEC* and RR-RL* were the only ones with a statistical resemblance (p-value > 0.05).

5.3.2.3 Analysis of the COP mean velocity

The mean velocity of the COP signals was calculated and analyzed using boxplot graphics. Mean velocity's parameter was considered in both directions and the tables with the p-values obtained from the Wilcoxon Test, were created (see appendix F). This test is used to compare changes between the nine tasks and a p-value superior to 0.05 is considered to represent a strong relation.

Analyzing the boxplot graphic, it is important to refer that a bigger dispersion is presented in the tasks RR*, RL* and RC*, for both directions (see figure 5.12 and 5.13). Moreover, the number of outliers decreased in the y direction.

The dispersion, mean and median values were very similar in the first six tasks, being the mean and median values of approximately zero.

Through the boxplot graphic of mean velocity in the y direction (see figure 5.13), it was possible to concluded that tasks RR*, RL* and RC* have mean and median values around the 20 mm/s. Thus, for this direction and for these 3 tasks, subjects have found it more difficult to maintain their balance.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

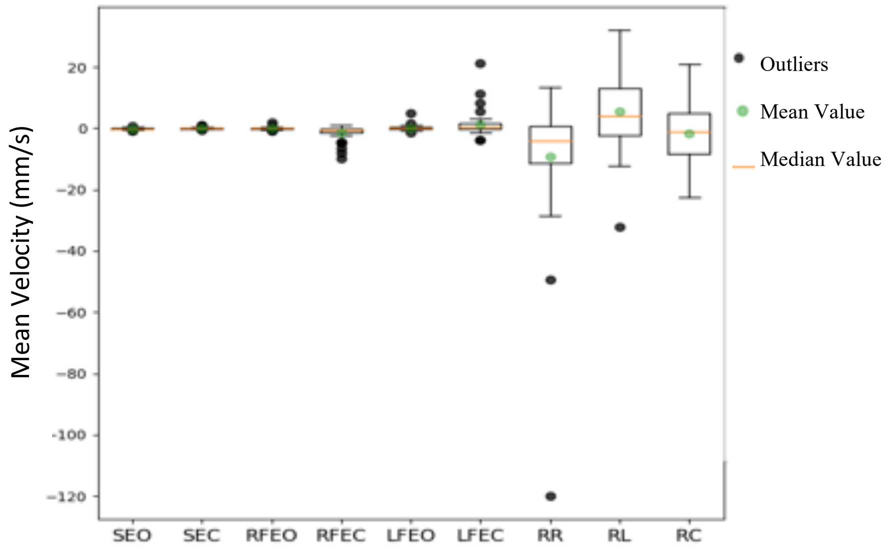


Figure 5. 13 - Boxplot with the representation of COP's mean velocity in the x direction, concerning the healthy sample.

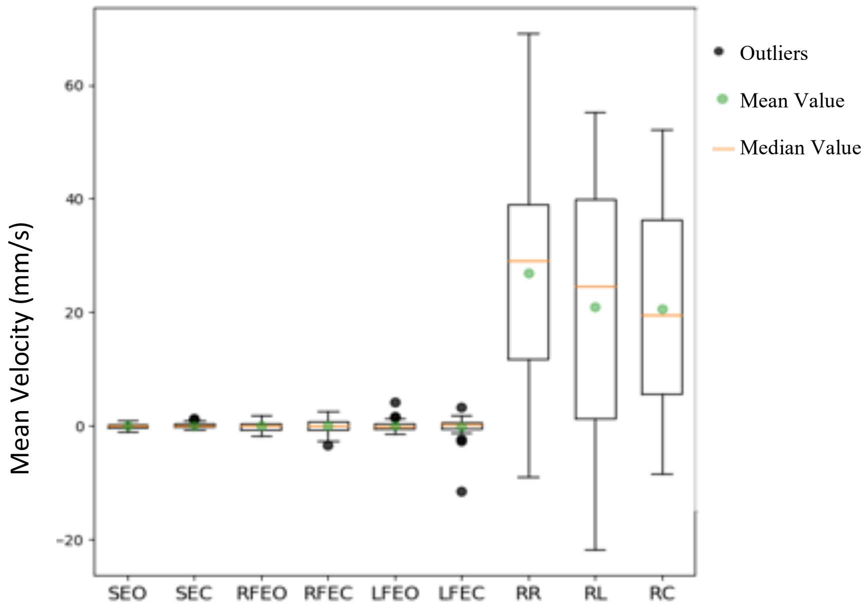


Figure 5. 13 - Boxplot with the representation of COP's mean velocity in the y direction, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Regarding the x direction, the tasks with no differences between them (p-value>0.05) were: SEO-SEC*, SEO-RFEO*, SEO-RC*, SEC-RFEO*, SEC-LFEO*, SEC-RC*, RFEO-LFEO*, RFEO-RC*, RFEC-RC* and LFEO-RC* (see appendix F).

The p-values obtained for the y direction indicate that a few pairs of tasks presented no significant changes (p-value>0.05), such as, SEO-SEC*, SEO-RFEO*, SEO-RFEC*, SEO-LFEO*, SEO-LFEC*, SEC-RFEO*, SEC-RFEC*, SEC-LFEO*, SEC-LFEC*, RFEO-RFEC*, RFEO-LFEO*, RFEO-LFEC*, RFEC-LFEO*, RFEC-LFEC*, LFEO-LFEC*, RR-RL* and RL-RC* (see appendix F).

5.3.2.4 Analysis of the COP total area

The total area was calculated, and the boxplot graphics were used to analyze the results. For all the nine tasks, the p-values were obtained using the Wilcoxon Test and a strong relation is represented by a p-value superior to 0.05.

After analyzing the boxplot represented in figure 5.14, one can concluded that SEO* and SEC* tasks presented the lower dispersions and the smaller mean and median values. The RFEC* and LFEC* tasks had the bigger boxplot sizes and higher values, of all nine tasks. Also, the pairs of tasks RFEO-LFEO* and RFEC-LEFC* had similar representations of the parameters analyzed. A few outliers were found in this graphic.

Regarding the p-values obtained, the pairs of tasks that presented no significant changes (p-value>0.05) were RFEO-LFEC*, LFEO-RR*, LFEO-RC*, RR-RL* and RL-RC* (see appendix F).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

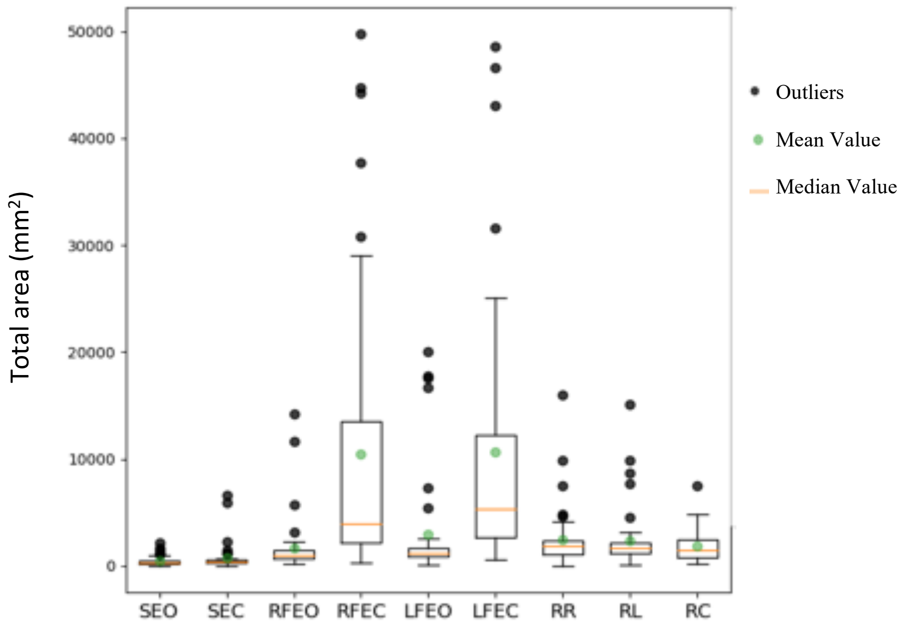


Figure 5. 14 - Boxplot with the representation of COP's total area, concerning the healthy sample.

5.3.2.5 Analysis of the COP frequencies

The mean and the 80% of power spectrum frequencies were calculated and the Wilcoxon Test was used to compare if there were any significant changes between tasks. A p-value superior to 0.05 was considered to represent a strong relation.

Results for the mean frequency were more similar in the x and the y directions. On the other hand, the 80% of power spectrum frequency were the more distinct ones.

In figures 5.15 and 5.16, the mean frequency is represented for the x and y directions. The tasks SEO* and SEC* presented the bigger dispersions and the higher values, and the RFEC* and LFEC* had the lower dispersions and values, for both directions. Overall, both boxplot graphics representing the tasks with one leg on the platform and with no visual information, had similar results.

Through the analysis of the p-values obtained for mean frequency in the x direction, no significant changes were found between (p-value>0.05) between SEO-SEC*, RFEO-LFEO*, RFEO-RC*, RFEC-LFEC*, LFEO-RR* and LFEO-RC* pairs of tasks (see appendix G).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

For the y direction, the pairs of tasks with no differences between them were: RFEO-LFEO*, RFEC-LFEC*, RFEC-RR*, RFEC-RL*, RFEC-RC*, LFEC-RR*, LFEC-RL*, LFEC-RC*, RR-RL*, RR-RC* and RL-RC* (see appendix G).

Concerning the results for both directions, the tasks SEO* and SEC* were statistically different from all the others (p-value<0.05).

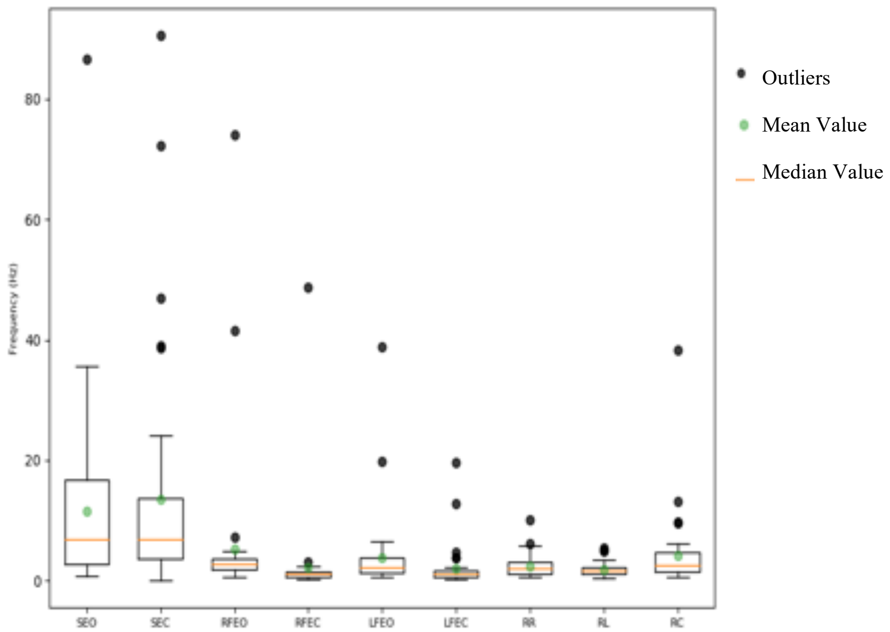


Figure 5. 15 - Boxplot with the representation of the mean frequency in the x direction, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

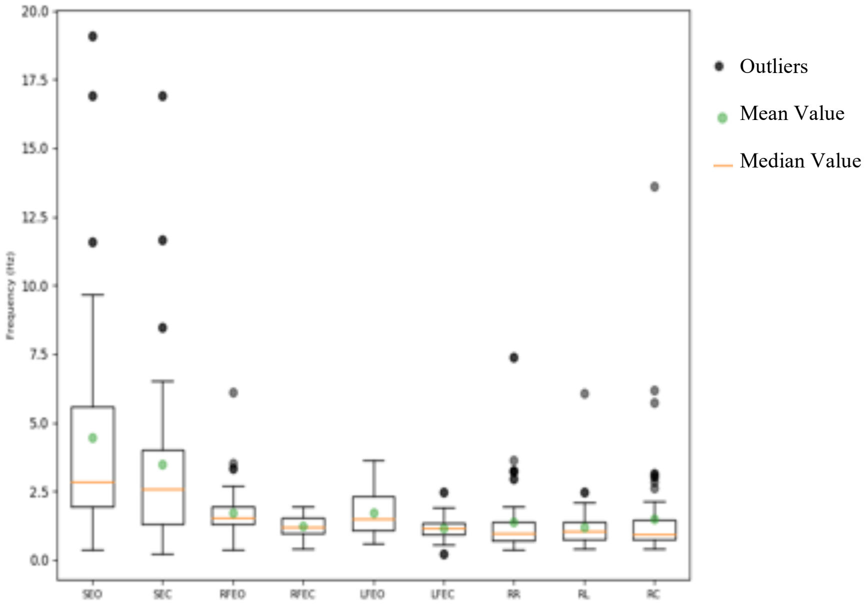


Figure 5. 16 - Boxplot with the representation of the mean frequency in the y direction, concerning the healthy sample.

Regarding the 80% of power spectrum frequency, some differences between directions could be noticed (see figures 5.17 and 5.18). In the y direction, the lowest mean and median values were observed, and an inferior number of outliers were noticed.

It was possible to observe that the SEO* and SEC* tasks have smaller dispersions in both directions.

No significant changes between tasks in the x direction were observed (p-value>0.05) for: RFEO-RFEC*, RFEO-LFEO*, RFEO-LFEC*, RFEO-RC*, RFEC-LFEO*, RFEC-LFEC*, RFEC-RL*, RFEC-RC*, LFEO-LFEC*, LFEO-RC*, LFEC-RR*, LFEC-RC* and RR-RL* (appendix G).

For the y direction, the pair of tasks without significant changes between them (p-value>0.05) were: RFEO-LFEO*, RFEO-RR*, RFEO-RL*, RFEO-RC*, RFEC-LFEC*, LFEO-RR*, LFEO-RL*, LFEO-RC*, RR-RL*, RR-RC* and RL-RC*.

SEO* and SEC* tasks were statistically different from all the tasks, for both directions (p-value<0.05) (appendix G).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject’s right side, with his left hand; **RL** = Reaching an object on the subject’s left side, with his right hand; **RC** = Reaching an object in front of the subject’s dominant hand;

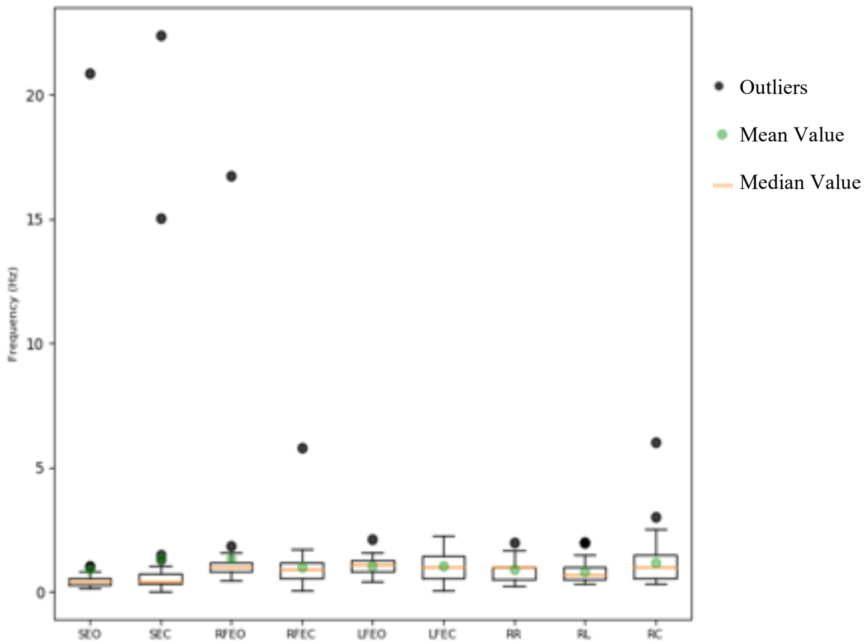


Figure 5. 18 - Boxplot with the representation of the 80% of power spectrum frequency of COP signals, in the x direction, concerning the healthy sample.

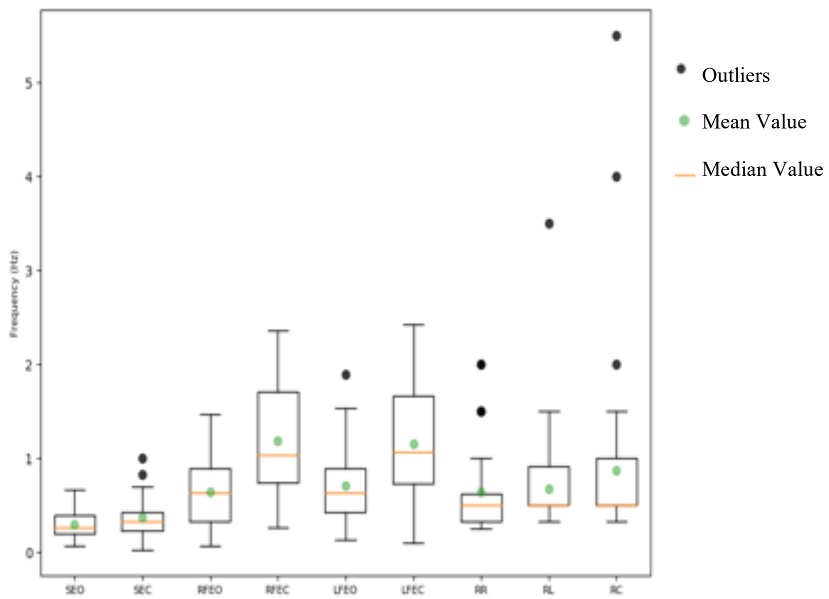


Figure 5. 17 - Boxplot with the representation of the 80% of power spectrum frequency of COP signals, in y direction, concerning the healthy sample.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.4.1 EMG data results

In order to understand the reliability of the tests results, 43 healthy subjects were submitted to the same protocol, one day after the first test. The results from test and retest were used in the paired samples t-Test, to analyze if the results were similar and reliable of being used in a clinical environment.

5.4.1.1 Analysis of the Mean and Median Values of the EMG arrays

For each task and each muscle, the mean and median value were calculated from retests data. With results from the two tests, the statistical analysis was made.

It is possible to observe in table 5.3, the p-values obtained using the paired samples t-Test for mean values.

No significant differences were observed between the values of both tests, for every task and muscle studied. The Multifidus right and left, for the tasks RFEO* and RFEC*, revealed to be the most reliable values obtained.

Table 5.3 - Representation of p-values from paired samples t-Test for mean values, concerning the healthy patients' results.

	RAL[A)]	RAR[A)]	OL[A)]	OR[A)]	IL[A)]	IR[A)]	ML[A)]	MR[A)]
RFEO*	0.3060	0.5657	0.2250	0.3392	0.3688	0.4776	0.2297	0.9676
RFEC*	0.4671	0.4690	0.0738	0.5702	0.7996	0.8234	0.3107	0.9540
LFEO*	0.2380	0.4888	0.1302	0.8765	0.2724	0.8054	0.6973	0.2497
LFEC*	0.8728	0.4106	0.1078	0.8327	0.2703	0.4122	0.6588	0.6375
SEO*	0.3933	0.2893	0.1250	0.5357	0.6282	0.2198	0.3069	0.3256
SEC*	0.3159	0.6478	0.2180	0.4374	0.2534	0.8909	0.8013	0.8298
RL*	0.2662	0.8760	0.1024	0.7931	0.1534	0.1814	0.7959	0.6159
RC*	0.5766	0.0677	0.1240	0.5391	0.3294	0.0658	0.1276	0.3105
RR*	0.2146	0.6259	0.8765	0.4482	0.2462	0.3625	0.1753	0.6583

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Concerning the median values, in the table 5.4 are represented the p-values obtained from the paired samples t-Test.

It was possible to confirm a strong relation between both tests, since no changes were found between the tests. The lowest p-values were found for Multifidus left and External Oblique left.

Table 5.4 - Representation of p-values from paired samples t-Test for median values, concerning the healthy patients' results.

	RAL[A)]	**RAR[A)]**	**OL[A)]**	**OR[A)]**	**IL[A)]**	**IR[A)]**	**ML[A)]**	**MR[A)]**
RFEO*	0.3596	0.6100	0.4175	0.5798	0.3111	0.8938	0.0468	0.8153
RFEC*	0.3584	0.5584	0.1198	0.6314	0.7055	0.5456	0.2894	0.1868
LFEO*	0.4955	0.5535	0.0814	0.8702	0.2733	0.5572	0.2995	0.2979
LFEC*	0.7554	0.5107	0.0561	0.4707	0.3572	0.1987	0.0689	0.4332
SEO*	0.3792	0.3312	0.0668	0.6997	0.4446	0.7140	0.3143	0.3669
SEC*	0.3139	0.5637	0.1043	0.7690	0.2082	0.5924	0.8403	0.8175
RL*	0.2207	0.1463	0.0673	0.9723	0.1910	0.5567	0.1242	0.4266
RC*	0.5433	0.1355	0.0268	0.7757	0.4927	0.1072	0.1861	0.2493
RR*	0.2028	0.8323	0.9854	0.5073	0.3746	0.6083	0.2095	0.8585

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

5.4.1.2 Analysis of the EMG frequencies

For the peak, mean and median frequencies no bigger changes were verified (p-value>0.05), excepting:

- In the peak frequency, for the Multifidus right - task RC*;
- In the mean frequency, for the Multifidus right – task LFEC*;
- In the median frequency, for Multifidus right – task LFEC*.

These results can be consulted in appendix H

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Finally, the 80% of power spectrum frequency was also calculated and the paired samples t-Test was used to find the p-values. For this frequency, more changes between test and retest values were found (p-value<0.05).

It was possible to observe in table 5.5 that values obtained for the posterior trunk muscles, in RFEO*, REFC*, LFEC*, SEC*, RL* and RC* tasks, demonstrate that there were some significant differences.

Table 5.5 - Representation of p-values from paired samples t-Test for 80% of power spectrum frequencies, concerning the healthy patients' results.

	RAL[A)]	**RAR**[A)]	**OL**[A)]	**OR**[A)]	**IL**[A)]	**IR**[A)]	**ML**[A)]	**MR**[A)]
RFEO*	0.0940	0.3058	0.1345	0.6979	0.5216	0.3295	0.0231	0.1604
RFEC*	0.9934	0.8884	0.2062	0.0787	0.0438	0.3288	0.0878	0.9012
LFEO*	0.4433	0.8562	0.5491	0.8577	0.7723	0.7158	0.6065	0.7317
LFEC*	0.6740	0.7303	0.3302	0.5157	0.8320	0.9580	0.4010	0.0052
SEO*	0.5443	0.3748	0.4392	0.5224	0.0676	0.2995	0.1073	0.0973
SEC*	0.3875	0.7838	0.5453	0.2582	0.2751	0.7145	0.0247	0.0877
RL*	0.5253	0.6200	0.1380	0.8147	0.0167	0.2231	0.7759	0.0313
RC*	0.4051	0.9443	0.2827	0.1804	0.1060	0.0142	0.9744	0.0992
RR*	0.7435	0.5693	0.2269	0.9352	0.1265	0.5018	0.4193	0.2180

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.4.2 COP Analysis

5.4.2.1 Analysis of the COP amplitude

The COP amplitude was calculated from data of the posturography retests and subsequently, p-values were obtained from paired samples t-Test. The p-values superior to 0.05 were considered to represent no significant changes between test and retest values.

For both directions, no significant changes were detected between test and retest (p-value>0.05).

It was possible to verify the lowest p-values observed for COP amplitude in the x direction was for the RFEO* task. For the y direction, the smallest p-value was for the RC* task (see table 5.6).

Table 5.6 - Representation of p-values from paired samples t-Test for COP's amplitude in the x and y directions, concerning the healthy patients' results.

	AMPLITUDE (X DIRECTION)	AMPLITUDE (Y DIRECTION)
RFEO*	0.0940	0.3265
RFEC*	0.9934	0.9574
LFEO*	0.4433	0.2295
LFEC*	0.6740	0.6628
SEO*	0.5443	0.3790
SEC*	0.3875	0.7205
RL*	0.5253	0.5373
RC*	0.4051	0.0805
RR*	0.7435	0.4766

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.4.2.2 Analysis of the COP standard deviation

The COP standard deviations were also calculated from the retests data, for both directions. The paired samples t-Test was applied to compare and analyze the changes between test and retest results and the p-values superior to 0.05 were considered to represent no significant changes.

In the table 5.7, the p-values from the statistical test in the x and y directions are presented. The resulting values were all superior to 0.05 and this led us to conclude that this parameter is reliable.

Table 5.7 - Representation of p-values from the paired samples t-Test for standard deviations of COP signals in the x direction, concerning the healthy patients' results.

	STANDARD DEVIATION (X DIRECTION)	**STANDARD DEVIATION (Y DIRECTION)**
RFEO*	0.6983	0.3684
RFEC*	0.3298	0.8584
LFEO*	0.3278	0.7726
LFEC*	0.4330	0.9542
SEO*	0.5652	0.7126
SEC*	0.2098	0.6291
RL*	0.5623	0.5791
RC*	0.7525	0.1171
RR*	0.9872	0.8753

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.4.2.3 Analysis of the COP mean velocity

The COP mean velocities in x and y were calculated one more time for retests results of the 43 healthy subjects. The paired samples t-Test was applied for both test and retest results in order to understand the reliability of these values.

The table 5.8 represents the p-values obtained from the statistical test for the x direction and for the y direction. For this parameter, no changes concerning test and retest results were verified since both tables have p-values superior to 0.05.

Table 5.8 - Representation of the p-values from the paired samples t-Test for mean velocity of COP signals in the x direction, concerning the healthy patients' results.

	MEAN VELOCITY (X DIRECTION)	**MEAN VELOCITY (Y DIRECTION)**
RFEO*	0.2479	0.5775
RFEC*	0.7078	0.8502
LFEO*	0.1802	0.2614
LFEC*	0.2704	0.5536
SEO*	0.5542	0.5432
SEC*	0.6458	0.7926
RL*	0.5808	0.9377
RC*	0.9671	0.4610
RR*	0.5046	0.7654

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.4.2.4 Analysis of the COP total area

The total area was calculated from retest data and a posterior statistical analysis was made with both test and retest results. The p-values obtained are represented in table 5.9. No significant differences between values from the two tests were found (p-value>0.05).

Table 5.9 - Representation of the p-values from the paired samples t-Test of COP total area, concerning the healthy patients' results.

	TOTAL AREA
RFEO*	0.5775
RFEC*	0.8502
LFEO*	0.2614
LFEC*	0.5536
SEO*	0.5432
SEC*	0.7926
RL*	0.9377
RC*	0.4610
RR*	0.7654

5.4.2.5 Analysis of the mean and the 80% of power spectrum frequencies in COP signals

The mean and the 80% of power spectrum frequencies were calculated from retests data and analyzed for both x and y directions. Afterwards, the paired samples t-Test was applied for these two parameters and no significant differences between values were detected.

In the table 5.10 are represented the p-values for the mean frequency in both directions and it was possible to observe that the SEO* task had the lowest values.

The lowest value observed for 80% of power spectrum frequency was in the LFEC* task, for the x direction (see table 5.11).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.10 – Representation of the p-values from the paired samples t-Test of COP mean frequency, concerning the healthy patients' results.

	MEAN FREQUENCY (X DIRECTION)	MEAN FREQUENCY (Y DIRECTION)
RFEO*	0.1805	0.8641
RFEC*	0.2771	0.7385
LFEO*	0.1858	0.8611
LFEC*	0.0625	0.5036
SEO*	0.0737	0.0553
SEC*	0.4195	0.3240
RL*	0.4041	0.8896
RC*	0.6190	0.5804
RR*	0.5522	0.3007

Table 5.11 – Representation of the p-values from the paired samples t-Test of COP 80% of power spectrum frequency, concerning the healthy patients' results.

	MEAN FREQUENCY (X DIRECTION)	MEAN FREQUENCY (Y DIRECTION)
RFEO*	0.3259	0.5575
RFEC*	0.2217	0.9274
LFEO*	0.1739	0.3827
LFEC*	0.0914	0.6934
SEO*	0.3264	0.6950
SEC*	0.4093	0.9016
RL*	0.2908	0.7307
RC*	0.5715	0.3914
RR*	0.4709	0.3630

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.5 Sample characterization–Stroke Patients

A group of 10 stroke patients participated in this study. Six of them were male and the other four were female. These patients were attending the CMRA and two of the criteria to select the group of patients participating in this study were:

1. Individuals with the ability to maintain upright standing position;
2. Individuals with cognitive ability and with no total aphasia.

Patients had to fill out a questionnaire before the acquisition, which made it possible to understand some important patient's characteristics (consult table 5.12).

All the 10 patients had their right hand as the dominant one, but only 5 patients used their dominant hand in the tasks of reaching an object – RR*, RL* and RC* tasks. Nine patients had post-stroke hemiparesis on the right side and only one patient had it on the left side.

Table 5.12 – Characterization of the stroke patients' group.

STROKE PATIENTS	AGE (YEARS)	HEIGHT (M)	WEIGHT (KG)
MEAN	55.7	1.72	79.5
STANDARD DEVIATION	11.7	0.097	14.5
RANGE	43.0 – 77.0	1.60 – 1.88	57.0 – 103

These patients were submitted to the same test twice, in order to understand if there were any differences from one test to another. Stroke patients were not able to execute the 9 tasks, therefore, the protocol had only 5 tasks– SEO*, SEC*, RL*, RR* and RC*.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.6 Analysis of postural parameters - Stroke Patients vs Healthy Subjects

5.6.1 EMG data results

5.6.1.1 Analysis of the Mean and Median Values of the EMG arrays

The mean and median values of the EMG arrays were also calculated for the group of stroke patients, allowing a comparison between the two samples.

When comparing healthy and stroke patients results, the Mann-Whitney test was used, where the p-values superior to 0.05 represent no significant differences between populations.

As stroke patients could only perform five of the nine tasks, of the initially proposed protocol, only these five tasks were compared with the healthy sample results.

For the mean and median activation values, bigger dispersions and higher values were observed in boxplot graphics representing the stroke sample, when comparing both populations (consult appendix I).

The most different results were visualized for the posterior trunk muscles, in both parameters evaluated. As an example, the Iliocostalis right had a p-value lower than 0.05 (see figure 5.19), for the task SEC*.

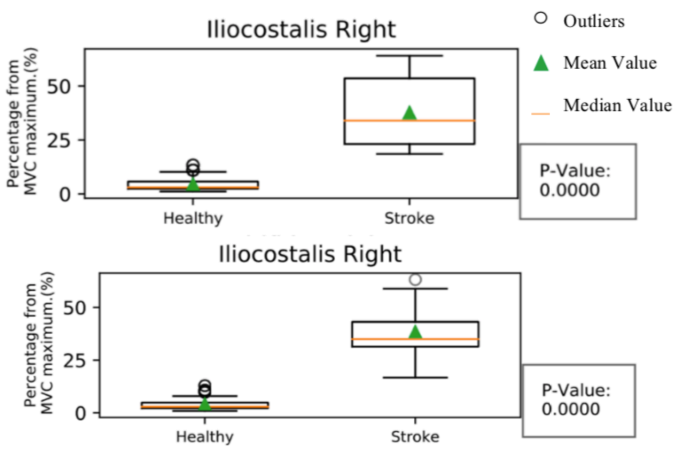


Figure 5. 19 – Representation of the mean and median values muscle activation for the SEC* task and p-values from the Mann-Whitney test, for the healthy and stroke populations, regarding the Iliocostalis right.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Still concerning the posterior trunk muscles, the results obtained for the Multifidus right indicated an increase of the activation values, for the stroke population.

For both mean and median values of the EMG arrays, significant differences were observed and confirmed by the statistical test (p-value<0.05) (see figure 5.20).

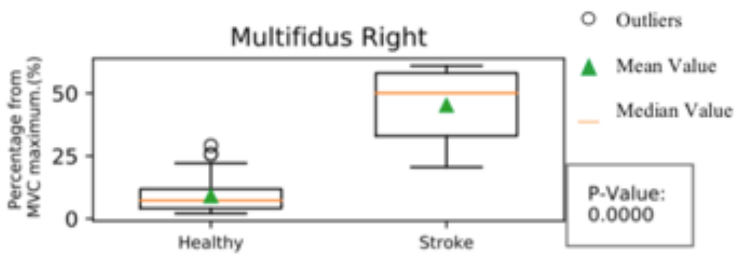


Figure 5. 20 – Representation of the mean value muscle activation for the SEC* task and p-values from the Mann-Whitney test, for the healthy and stroke populations, regarding Multifidus right.

Although the modified Ashworth scale was used to evaluate muscle spasticity, mean values of the muscle activation during rest were analyzed (see appendix J). This condition was studied in order to understand if the stroke patients had a lower or higher muscle tone and if it influenced the results analyzed before.

It is known that 9 of the 10 stroke patients had right hemiparesis. Thus, it was noticed that, for all muscles, especially the right ones, higher mean and median values were presented for these 9 patients.

It is important to mention that bigger dispersions were also noticed. This is possible to observe in the Iliocostalis right (see figure 5.21) and in the Multifidus right (see figure 5.22).

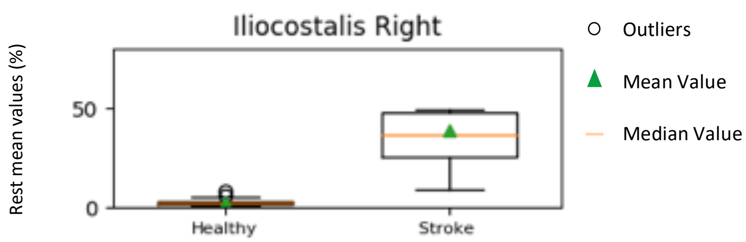


Figure 5. 21 – Representation of the mean value of the muscle activation, for the healthy and stroke populations, during rest.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

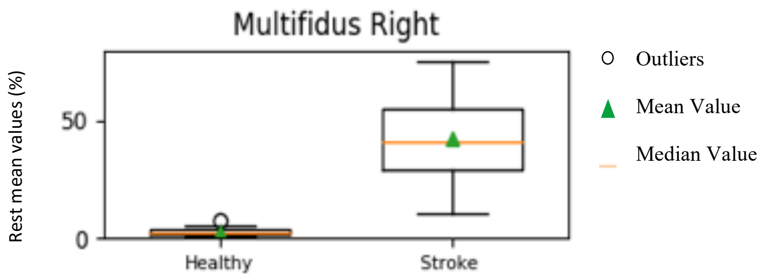


Figure 5. 22 – Representation of the mean value muscle activation during rest, for the healthy and stroke populations.

In regards to the median values of the EMG array, only in the SEC* tasks were found some similarities between the two samples, for the External Obliques (p-value>0.05) (see figure 5.23). For the other muscles, no similarities were noticed between the healthy subjects and the stroke patients and, in general, the activation values were higher for the stroke patients.

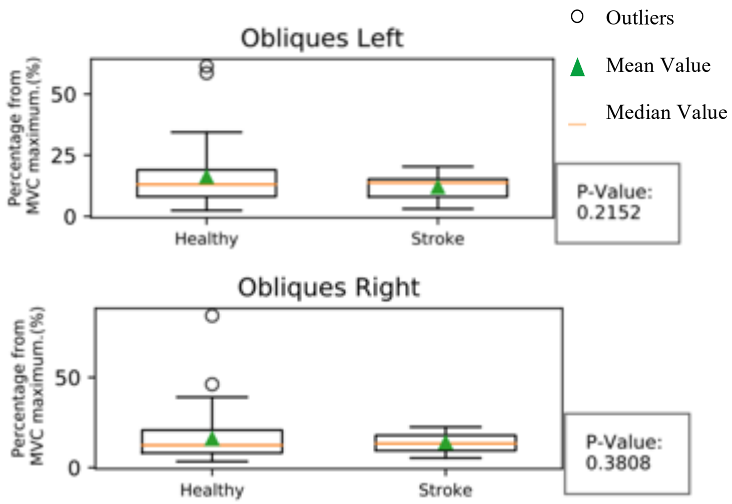


Figure 5. 23 – Representation of the median value muscle activation for the SEC* task and p-values from the Mann-Whitney test, for the healthy and stroke populations in External Obliques left and right.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.6.1.2 Analysis of the EMG frequencies

As for the anterior trunk muscles, through the 5 tasks analyzed, and comparing the two populations, some interesting results were observed (see appendix K), especially for the tasks SEO* and SEC*.

Comparing both groups, similar dispersions and values were detected for all the frequencies, in the results obtained for the External Obliques (see figure 5.24).

The mean and median frequencies had more results where no differences between the healthy and stroke samples values were detected (p-values>0.05).

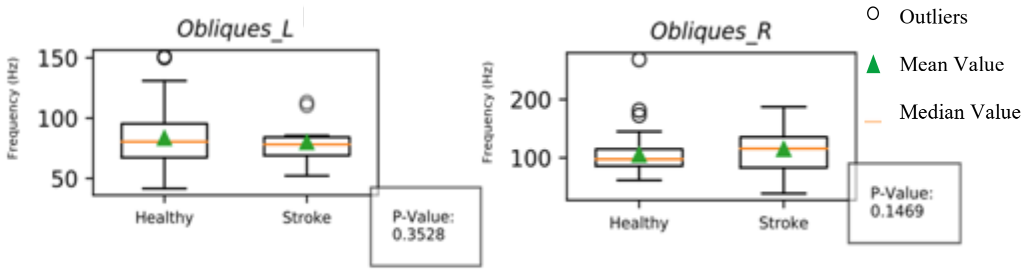


Figure 5. 24 – Representation of the mean frequencies, for the External Obliques and the task SEO*, and the p-values from the Mann-Whitney test, concerning the healthy and stroke populations.

The posterior trunk muscles were also analyzed and mean, peak, median and 80% of the power spectrum frequencies were obtained.

For the task SEO*, no significant differences were obtained between the results of the two samples studied, regarding the Multifidus left.

The task SEC* had the biggest dispersions concerning the Multifidus right.

When referring to the RL* and RC* tasks, there were similar values between both populations.

Finally, in the median and mean frequencies, higher values were observed for the stroke sample (see figure 5.25).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

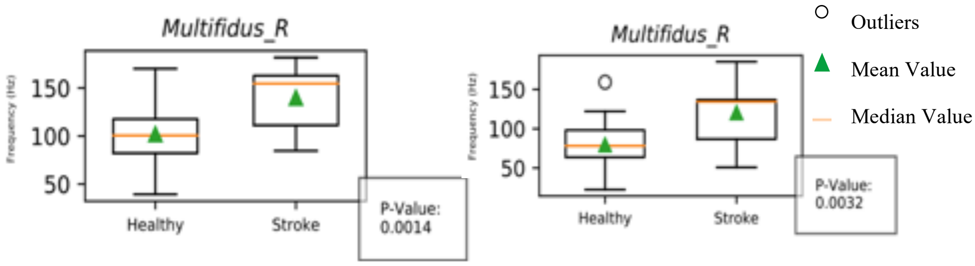


Figure 5. 25 – Representation of the mean (left boxplot) and the median (right boxplot) frequencies, regarding the Multifidus right for the task SEO*, and the p-values obtained from the Mann-Whitney test, concerning the healthy and stroke samples.

5.6.2 COP Analysis

5.6.2.1 Analysis of the COP amplitude

The COP amplitude was calculated for both populations, through the 5 tasks and some interesting differences were observed (see appendix L). There were significant differences between groups, for the tasks: SEO*, RR*, RC* and RL*.

After analyzing the results obtained from the Mann-Whitney test, the task SEC* was the only one with more similarities between healthy and stroke patients and for both directions (see figure 5.26 and 5.27). The tasks SEO* and RC* had p-values superior to 0.05 for the x direction.

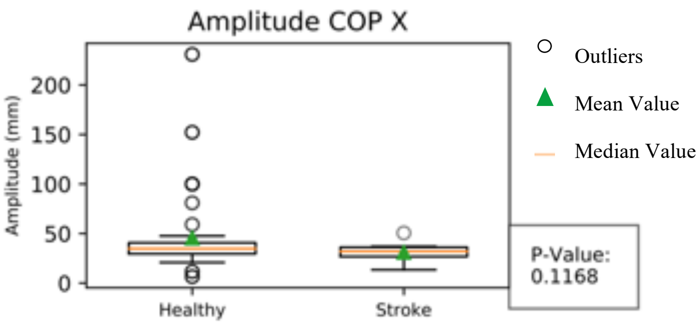


Figure 5. 26 – Representation of the COP amplitude, in the x direction and for the SEC* task, concerning the healthy and stroke samples.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

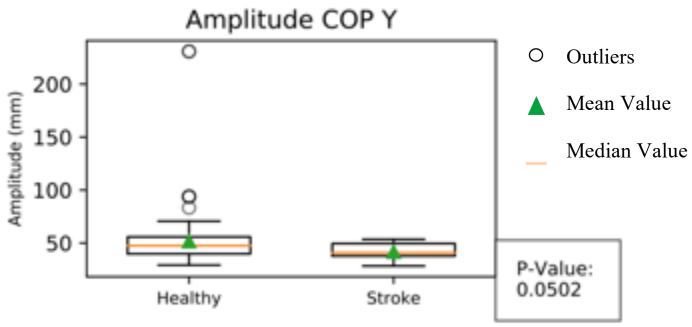


Figure 5. 27 – Representation of the COP amplitude, in the y direction and for the SEC* task, concerning the healthy and stroke samples.

5.6.2.2 Analysis of the COP mean velocity

Regarding the COP mean velocity (consult appendix L), it was noticeable that mean and median values were around the 0 mm/s for the task SEC* and for both samples. However, in the y direction and for the tasks SEO* and RC*, the values for the healthy population were slightly higher.

For the tasks RL* and RR*, the stroke sample obtained mean and median values superior to the 0 mm/s, which did not occur for the healthy sample.

When applied to the statistical test, some significant differences between both samples were observed in the y direction and for the tasks RR*, SEO* and RC*(p-value<0.05).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.6.2.3 Analysis of the COP standard deviation

The results regarding the COP standard deviation (consult appendix L) revealed no significant variances between both samples (p-value>0.05) for:

- The task SEC* in both directions;
- The task RC* in the x direction;
- The task RL* in the y direction.

However, for the task SEO*, some differences were detected by the statistical test applied. The mean and median values were superior for the healthy sample when compared with the results from the stroke population, in both directions.

5.6.2.4 Analysis of the COP total area

Concerning the results from the COP total area and comparing both populations, significant differences were detected between them, with the exception of the values obtained in the task SEC* (p-value>0.05) (see figure 5.28).

In four of the five tasks studied, stroke patient's total area turned out to be smaller. Only in the task RR* the mean and median values were rounding the 1000 mm^2, superior to the ones visualized for the healthy population.

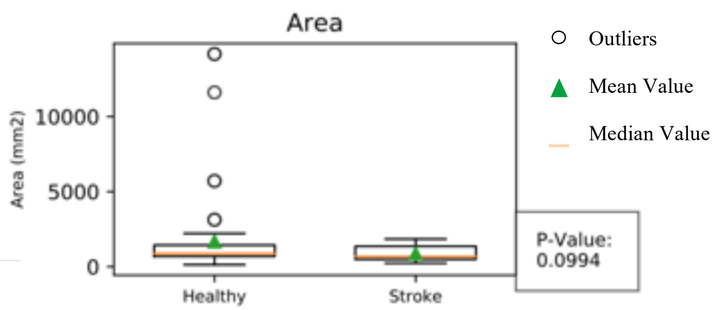


Figure 5. 28 – Representation of the COP total area for the task SEC*, and the p-value from the Mann-Whitney test, concerning the healthy and stroke populations.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.6.2.5 Analysis of the Mean and 80% of the power spectrum frequencies in COP signals

The results obtained for the mean frequency demonstrated bigger dispersions, mean and median values concerning the stroke patients, in both directions for the task SEO* and SEC* (see figure 5.29).

Significant differences between samples were observed for all the tasks, excepting the task RL* (p-value < 0.05).

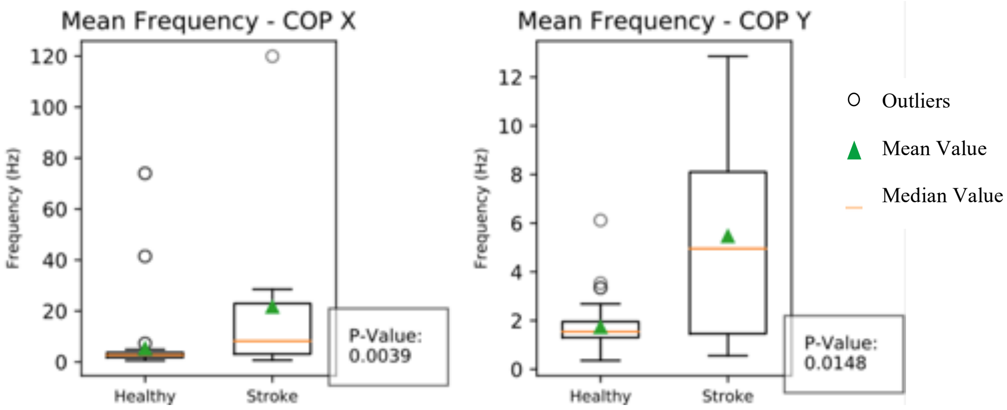


Figure 5. 29 – Representation of the mean frequency for the COP signals, in both directions for the task SEC*, and p-values from the Mann-Whitney test, concerning the healthy and stroke populations.

Regarding the 80% of the power spectrum frequency, in the y direction, the dispersion, the mean and median values were higher for the healthy population, for the task SEO* and SEC*.

For this parameter and when applying the statistical test, some significant differences were observed for a few tasks and directions, such as:

- The task SEO*, in both directions;
- The task SEC*, in the x direction;
- The task RC*, in the y direction.

The tasks RR* and RL* had p-values superior to 0.05 for both directions (see figure 5.30), suggesting no statistical differences.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

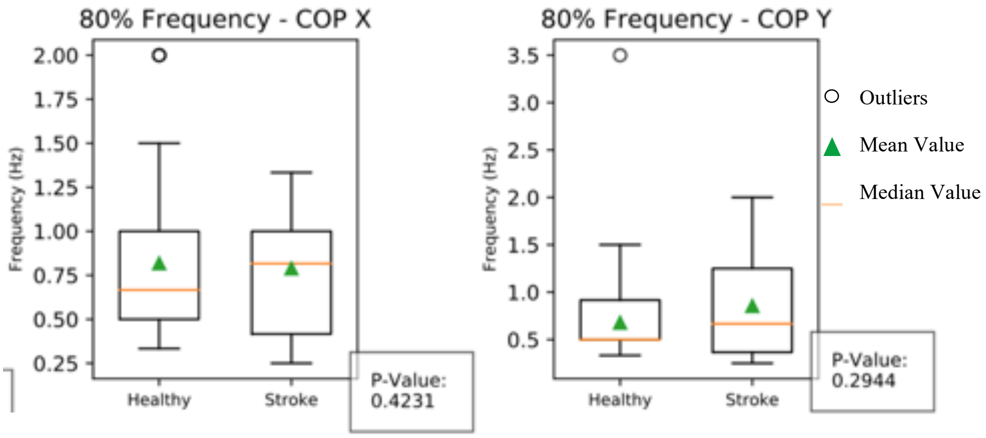


Figure 5. 30 – Representation of the 80% of the power spectrum frequency for the COP signals, in both directions for the task RR*, concerning the healthy and stroke samples.

5.7 Analysis of postural parameters - Stroke Subjects Test-Retest

The tests and retests were performed in the 10 stroke patients. Some of them made the retest the day after the test and others two, five, six and seven days after, according to the patient's availability.

5.7.1 EMG data results

5.7.1.1 Analysis of the Mean and Median Values of the EMG arrays

For each task and each muscle, the mean and median values were calculated. With results from the two tests, the statistical test was applied.

In table 5.13, it is possible to observe the p-values obtained using the paired samples t-Test for mean values of the muscles activation, and in table 5.14, the results for the median values.

As for these two parameters, no statistical differences were detected for all the muscles studied.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.13 – Representation of the p-values from the paired samples t-Test, for the mean values, concerning the stroke patients' results.

	RAL[A)]	**RAR**[A)]	**OL**[A)]	**OR**[A)]	**IL**[A)]	**IR**[A)]	**ML**[A)]	**MR**[A)]
SEO*	0.1642	0.8549	0.1522	0.5865	0.0930	0.7091	0.8589	0.3125
SEC*	0.8013	0.6343	0.7142	0.5937	0.1393	0.4160	0.9030	0.8848
RR*	0.3001	0.5739	0.8877	0.9566	0.5644	0.4527	0.4746	0.7076
RL*	0.4863	0.7616	0.2414	0.9675	0.5644	0.2793	0.8250	0.9890
RC*	0.7053	0.8436	0.7043	0.3149	0.2071	0.1757	0.9856	0.4945

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

Table 5.14 – Representation of the p-values from the paired samples t-Test, for the median values, concerning the stroke patients' results.

	RAL[A)]	**RAR**[A)]	**OL**[A)]	**OR**[A)]	**IL**[A)]	**IR**[A)]	**ML**[A)]	**MR**[A)]
SEO*	0.2259	0.8668	0.3014	0.4801	0.6691	0.3827	0.2802	0.2990
SEC*	0.5162	0.9912	0.0599	0.2094	0.0173	0.3130	0.5411	0.3572
RR*	0.1602	0.9258	0.0579	0.2307	0.7025	0.9660	0.5080	0.1669
RL*	0.3615	0.0864	0.2356	0.5977	0.7663	0.6938	0.6365	0.8597
RC*	0.8499	0.5813	0.6384	0.1116	0.0722	0.1377	0.0235	0.9106

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

5.7.1.2 Analysis of the EMG frequencies

In regards to the EMG frequencies, peak, mean, median and 80% of power spectrum frequencies were studied also with the retest data.

Afterwards, the paired samples t-Test was applied in order to understand if there were any differences between the patients' results.

The p-values obtained for the peak frequency were analyzed (see table 5.15) and some significant differences were detected in:

- The Multifidus left for the task RC*;
- The Iliocostalis left for the task SEC*;
- The External Obliques for the task SEC*.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.15 – Representation of the p-values from the paired samples t-Test, for the peak frequency, concerning the stroke patients' results.

	RAL A)	RAR A)	OL A)	OR A)	IL A)	IR A)	ML A)	MR A)
SEO*	0.9009	0.1875	0.9559	0.5041	0.7314	0.6604	0.2624	0.1149
SEC*	0.4762	0.8726	0.7864	0.0342	0.0486	0.3212	0.4806	0.0783
RR*	0.3592	0.4791	0.9241	0.4530	0.2181	0.3246	0.1937	0.9702
RL*	0.9571	0.7806	0.3159	0.3380	0.7352	0.6120	0.2606	0.9201
RC*	0.7732	0.5767	0.9876	0.3849	0.7624	0.9318	0.0155	0.2750

A) **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

Considering the mean frequency, some statistical differences were detected for (see table 5.16):

- The External Oblique right for the task SEO*;
- The Iliocostalis left for the task SEC*;
- The Multifidus right for the task SEO*.

Table 5.16 - Representation of the p-values from the paired samples t-Test, for the mean frequency, concerning the stroke patients' results.

	RAL A)	RAR A)	OL A)	OR A)	IL A)	IR A)	ML A)	MR A)
SEO*	0.9668	0.6243	0.5607	0.0344	0.1092	0.3375	0.1654	0.0363
SEC*	0.1974	0.4259	0.5885	0.1999	0.0031	0.6696	0.0769	0.1241
RR*	0.6024	0.4141	0.6705	0.2287	0.4451	0.6374	0.1906	0.2326
RL*	0.4481	0.9972	0.8759	0.0880	0.7095	0.6037	0.4776	0.9758
RC*	0.1952	0.2873	0.5867	0.2525	0.1639	0.0794	0.8628	0.5250

A) **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

When observing the results from the statistical test for the median frequency (see table 5.17), it was possible to understand that some significant differences between results were detected for:

- The Iliocostalis right for the tasks RL*, RC* and RR*;
- The Iliocostalis left for the tasks SEC* and RR*;
- The Multifidus left for the tasks RR* and RC*.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.17 – Representation of the p-values from the paired samples t-Test, for the median frequency, concerning the stroke patients' results.

	RAL[A)]	RAR[A)]	OL[A)]	OR[A)]	IL[A)]	IR[A)]	ML[A)]	MR[A)]
SEO*	0.6630	0.8186	0.6750	0.0823	0.6851	0.8400	0.1514	0.2331
SEC*	0.7180	0.1252	0.7655	0.7842	0.0061	0.5690	0.1011	0.3143
RR*	0.9783	0.1428	0.4030	0.2871	0.0326	0.0100	0.0127	0.4433
RL*	0.8805	0.9011	0.5984	0.4131	0.4167	0.0392	0.0987	0.3494
RC*	0.1351	0.3280	0.3059	0.1131	0.3957	0.04320	0.0204	0.3706

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

Finally, the 80% of power spectrum frequency was analyzed and the statistical test was applied (see table 5.18).

For this parameter, significant differences were observed in:

- The Rectus Abdominis right for the task RR*;
- The External Oblique left for the task RR*;
- The External Oblique right for the task RL*;
- The Iliocostalis right for the task RL*.

Table 5.18 – Representation of the p-values from the paired samples t-Test, for the 80% of power spectrum frequency, concerning the stroke patients' results.

	RAL[A)]	RAR[A)]	OL[A)]	OR[A)]	IL[A)]	IR[A)]	ML[A)]	MR[A)]
SEO*	0.9091	0.4763	0.3499	0.1903	0.9189	0.7643	0.7705	0.1403
SEC*	0.0520	0.0932	0.7570	0.0112	0.7291	0.0637	0.1170	0.1020
RR*	0.4523	0.0032	0.0164	0.1156	0.7253	0.1340	0.0766	0.1203
RL*	0.1365	0.1921	0.0670	0.0010	0.0909	0.0244	0.1883	0.6920
RC*	0.2459	0.0774	0.0931	0.0124	0.5048	0.1825	0.3039	0.8688

[A)] **RAR** = Rectus Abdominis Right; **RAL** = Rectus Abdominis Left; **OR** = External Obliques Right; **OL** = External Obliques Left; **IR** = Iliocostalis Right; **IL** = Iliocostalis Left; **MR** = Multifidus Right; **ML** = Multifidus Left.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.7.2 COP Analysis

5.7.2.1 Analysis of COP amplitude

The COP amplitude was calculated from data acquired in the retests and the statistical test was applied. The values superior to 0.05 were considered to represent no significant changes between the two tests values.

It is possible to observe the p-values for the COP amplitude in both directions in table 5.19 and understand that there were no significant differences between the values from both tests (p-value>0.05).

Table 5.19 – Representation of the p-values from the paired samples t-Test, for the COP amplitude in the x and y directions, concerning the stroke patients' results.

	AMPLITUDE (X DIRECTION)	**AMPLITUDE (Y DIRECTION)**
SEO*	0.4770	0.5908
SEC*	0.9455	0.3877
RR*	0.2588	0.1082
RL*	0.4339	0.4912
RC*	0.8693	0.4279

5.7.2.2 Analysis of COP standard deviation

Regarding the standard deviations calculated from the COP signals recorded in both tests, the paired samples t-Test was applied to understand the statistical relation between the results from the two tests.

The p-values obtained for the x and y directions represent no statistical differences between both tests' values (see table 5.20).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.20 – Representation of the p-values from the paired samples t-Test, for the COP standard deviation in the x and y directions, concerning the stroke patients' results.

	STANDARD DEVIATION (X DIRECTION)	STANDARD DEVIATION (Y DIRECTION)
SEO*	0.4770	0.5908
SEC*	0.9455	0.3877
RR*	0.2588	0.1082
RL*	0.4339	0.4912
RC*	0.8693	0.4279

5.7.2.3 Analysis of COP mean velocity

Another parameter studied is the mean velocity calculated from the COP signals. With results from both tests, it was possible to apply the statistical test and to understand that no significant differences were detected in both directions (see tables 5.21).

Table 5.21 – Representation of the p-values from the paired samples t-Test, for the COP mean velocity in the x and y directions, concerning the stroke patients' results.

	MEAN VELOCITY (X DIRECTION)	MEAN VELOCITY (Y DIRECTION)
SEO*	0.5199	0.6637
SEC*	0.2919	0.8275
RR*	0.1201	0.5773
RL*	0.1036	0.4335
RC*	0.2757	0.4578

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

5.7.2.4 Analysis of COP total area

Concerning the COP parameters, it is important to analyze the COP total area and the results from the paired samples t-Test.

The statistical test demonstrated that there are no significant differences between tests (see table 5.22).

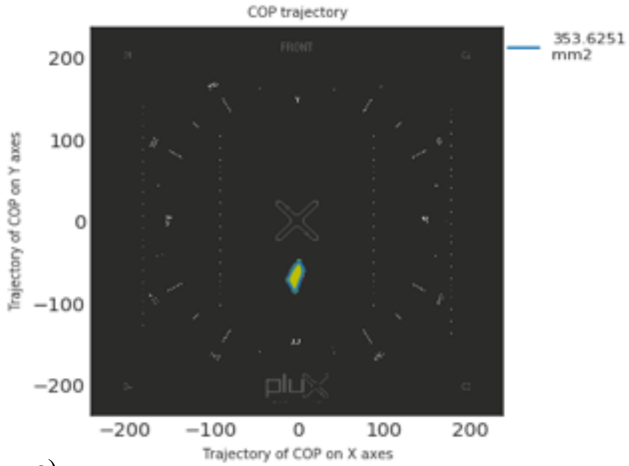
Table 5.22 – Representation of the p-values from the paired samples t-Test, for COP total area, concerning the stroke patients' results.

	TOTAL AREA
SEO*	0.7690
SEC*	0.6488
RR*	0.2732
RL*	0.5355
RC*	0.9181

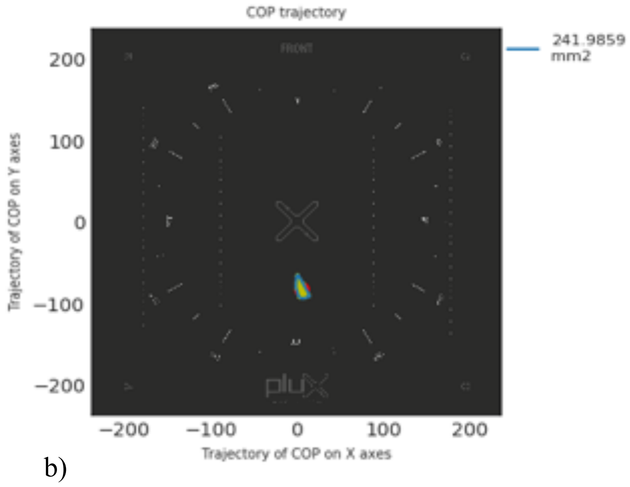
In order to better analyze this parameter, some images representing the COP total area from stroke patients are now presented, individually. In the figure 5.31 are represented the results from the only patient with left hemiparesis, regarding the task SEC*. This patient presented a total area of 353.6251 mm^2, in the first test, and the value acquired for retest was 241.9859 mm^2.

Other individual cases can be consulted in appendix M.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;



a)



b)

Figure 5. 31 – Representation of the COP total area a) results from test and b) results from retest, for the SEC* task, concerning the only patient with left hemiparesis.

5.7.2.5 Analysis of COP frequencies

The mean and the 80% of power spectrum frequencies were also calculated from retest data and the statistical test was applied, as it was previously done.

For these two frequencies and in both directions, no significant differences between results from both tests were noticed (p-value >0.05) (see table 5.23 and 5.24).

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Table 5.23 – Representation of the p-values from the paired samples t-Test, for the COP mean frequency in the x and y directions, concerning the stroke patients' results.

	MEAN FREQUENCY (X DIRECTION)	MEAN FREQUENCY (Y DIRECTION)
SEO*	0.8107	0.5319
SEC*	0.6397	0.8148
RR*	0.2903	0.6385
RL*	0.5482	0.4985
RC*	0.2860	0.7587

Table 5.24 - Representation of the p-values from the paired samples t-Test, for the COP 80% of power spectrum frequency in the x and y directions, concerning the stroke patients' results.

	80% OF THE POWER SPECTRUM FREQUENCY (X DIRECTION)	80% OF THE POWER SPECTRUM FREQUENCY (Y DIRECTION)
SEO*	0.2640	0.3538
SEC*	0.4780	0.1708
RR*	0.1984	0.6825
RL*	0.1833	0.1081
RC*	0.3629	0.2841

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Chapter 6

6. Discussion

The main goals of this study were to increase a previous database of healthy subjects, perform test and retests to assess the protocol's reliability and to identify and evaluate postural adjustments in a stroke patients' sample. When aiming to assess postural control and balance in stroke patients, it is important to have a reliable healthy postural profile so that the stroke patients' results can be compared with this healthy profile.

Increasing the healthy database was possible due to the participation of 43 healthy subjects. This sample performed two times the nine tasks protocol and so, made it possible to complete the first two main objectives of this study. Therefore, the results from the healthy sample will be now discussed.

- **Healthy sample results**

Regarding the healthy group and their results of muscles activation, it was possible to notice that the mean and median values of muscles activation for Rectus Abdominis maintained similar for all the standing tasks. As for both External Obliques throughout the nine tasks, the highest mean and median activation values were observed.

These results suggest that during a standing position, muscles from the anterior abdominal have an important role in maintaining standing postures, consistent with what was observed in O'Sullivan et al. [54].

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Although for muscle activation on the right side, a slightly superior mean and median values were noticed, for the anterior trunk muscles, these values were not significantly different from the left side. One may conclude that muscles from both sides work together to guarantee a stable standing posture.

Concerning the healthy sample's results and the EMG frequencies, no significant differences between tasks were observed for the Rectus Abdominis left and right. In general, the p-values obtained were all superior to 0.05 for mean, median, peak and 80% of power spectrum frequencies. For the other muscles, the same results were observed in the four frequencies. This information strengthens the conclusion that the Rectus Abdominis have a strong roll in postural control in a standing position.

For the remaining muscles studied (Multifidus, Iliocostalis and External Obliques), it was detected that the pairs of tasks RFEO-RFEC* and LFEO-LFEC* presented significant differences between them (p-value<0.05). The lack of visual information can trigger changes in the postural control and in the ability to stay balanced. As lower mean and median values were noticed for the tasks with eyes closed (RFEC* and LFEC*), it is possible to conclude that subjects had more difficulties executing the tasks with no visual information.

When analyzing the COP results, some concordant information was noticed, with what was found by Dault et al. [48]. In their study, we can see that the COP amplitude increased, and the frequencies decreased, with no visual feedback. Concerning the 43 healthy subjects participating in this study, a significant increase of the COP amplitude was observed, in both directions for the tasks with no visual feedback. The observation of an increase of the mean and median values is seen, which enables one to conclude that the ability to control posture and balance is lost when no visual information is sent to the postural control system.

The mean velocity parameter had very similar results for both x and y directions. The SEO*, SEC*, RFEO*, RFEC*, LFEO*, and LFEC* tasks had values around the 0 mm/s, which are representative of a good ability to preserve stability. It is possible to conclude that a person's body can maintain a correct position, even when it is experiencing some destabilization or with some impairments, such as, not having visual information and performing a task with only one foot on the platform.

It is important to understand that greater difficulties appear when a subject tries to preserve a stable posture while performing a task with only one foot on the platform and with no visual feedback.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Concerning the tasks with the eyes closed, the SEC* task did not present the same behavior when compared with RFEC* and LFEC* tasks. The tasks RFEC* and LFEC* presented big boxplot dispersions, similar mean and median values in the total area parameter. Additionally, no big boxplot dispersions and values were detected for the tasks SEC* and SEO*. Thus, this indicates that to preserve balance, when being in a stable position, it is not significantly different having or not having visual information.

COP frequencies in both directions presented some interesting boxplot graphics. While, in the x direction and for the 80% of power spectrum frequency, the mean and median values were similar for the nine tasks, in the y direction, the tasks RFEO*/RFEC* and LFEO*/LFEC* had the biggest dispersions as well as the higher mean and median values. The tasks performed with one foot and no visual information were the ones with the most superior values and dispersion. Regarding the mean frequency in both directions, the tasks SEO*, SEC*, RFEO* and LFEO* had the higher mean and median values.

- **Healthy subjects – Tests and Retests results**

All the 43 healthy subjects performed the same protocol twice and so it was possible to assess the reliability of the tests results. To understand the relation between the results from both tests, the paired samples t-Test was applied. A p-value superior to 0.05 indicated that there were no significant differences between data from test and retest. For mean and median activation values, almost all of the p-values obtained from the paired samples t-Test were superior to this specified value.

When analyzing the p-values obtained for the data related with EMG frequencies, there were no significant statistical differences. On the other hand, the 80% of power spectrum frequency presented a higher number of p-values that were inferior to 0.05, regarding the posterior trunk muscles. Results from both tests demonstrated a few differences for the data concerning the posterior trunk muscles.

Furthermore, data from COP parameters - amplitude, standard deviation, total area and mean velocity -, and from COP frequencies – mean and the 80% of power spectrum frequencies -, presented no significant differences between test and retest results.

These statistical results suggest that data acquired in this study is reliable, can be used and analyzed in a clinical context.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

To help stroke patients and their rehabilitation process, it is essential to evaluate their postural adjustments and compare them with a healthy sample. In this study, 10 stroke patients executed only five tasks of the protocol performed by the healthy sample, due to the incapability of performing the other four tasks – RFEO*, RFEC*, LFEO* and LFEC*.

When analyzing the stroke patients' results, some interesting values were detected and a comparison between the healthy sample and the stroke sample was made.

- **Stroke patients results and a comparison with the results of the healthy subjects**

Comparing the muscle activation values for the stroke sample, the Rectus Abdominis presented the lowest mean and median values. These values were also similar for the 5 tasks, suggesting a constant and similar activation of this group of muscles throughout the protocol. Although these results were considered low in the stroke sample, they were higher than the ones obtained for the healthy population.

When observing the possible similarities between the muscle activation values of the healthy subjects and the stroke patients, it was noticed that only the values of the External Obliques did not reveal any significant differences (p-values>0.05).

The posterior trunk muscles in stroke patients presented the higher mean and median values, from all the 4 group of muscles and for all the 5 tasks, However, these results were not detected for the healthy sample.

To understand these different activation values of both groups, the mean values were obtained from the data recorded during a resting period. That way, it was possible to understand that a higher muscle tone was observed in all the stroke patients' muscles on the right side, which was expected since 9 of the 10 patients were diagnosed with right hemiparesis.

As for the EMG frequencies and concerning the stroke patients' posterior trunk muscles, the task SEC* presented a lower mean frequency when compared to the task SEO*, with visual information.

When comparing the frequencies results from both samples and concerning the anterior trunk muscles, it was observed that the median and mean values, obtained from the boxplot graphics for the stroke patients, were lower than those obtained for the healthy sample.

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Evaluating the COP parameters, no significant differences were observed between the two samples studied, for the SEC* task.

The COP amplitude was small in the y direction, for the task SEC*, and the mean velocity increased, suggesting that stroke patients were able to maintain an upright standing position without major complications. These results were not expected for the stroke sample, considering that in these patients with diagnosed hemiparesis it is quite common to visualize greater body sway and postural instability, even if there is visual information.

When comparing both healthy subjects and stroke patients, no similarities were detected between populations for the SEO* task since the healthy population had a higher COP amplitude dispersion, which was not expected. Meanwhile, looking closely to the results obtained for the stroke patients, mean velocities in the x and y directions go around the 0 mm/s, which is a little different from what happens for the healthy population in this referred task.

Focusing on the stroke patients' results and on the task SEC*, a bigger dispersion was observed in the mean velocities, indicating that without visual information some postural adjustments had to be done to guarantee the body's stability. These findings are related to what was demonstrated in Niam et al. [63] study. A greater postural sway in tasks with eyes closed and in a quiet stance position is observed.

Total area is another parameter where some differences between the two group samples were detected, for almost every task, excepting the task SEC*. Comparing both samples, the total area values of the stroke patients were lower for the task SEO*, and very similar for the task SEC*. It is important to understand that these results were not expected as it was previously thought that it would be more difficult for the stroke patients to maintain an upright standing position. Thus, they would display a bigger body sway and mean velocities, especially for the SEC* task.

As for the COP frequencies, the Mann-Whitney test was applied, and it was observed that the task RL* task presented no statistical differences between the two populations. This was not consistent for the other tasks, which suggest that the postural responses from the stroke group are different from the ones observed in the healthy sample.

It was possible to compare the COP total area results from one stroke patient with left hemiparesis and the ones obtained for a stroke patient with right hemiparesis. With this analysis it was concluded that no differences were noticed between the two patients.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

The patient with left hemiparesis did not demonstrate any differences in his COP trajectory, during the SEO* and SEC* tasks, and the placement of his feet on the platform was similar to what was observed for the right hemiparesis patients.

It would be expected that left hemiparesis patients had different postural adjustments from the right hemiparesis patents, so it is essential to study a larger sample of stroke patients with left hemiparesis and to initiate all the test in the same feet position, in order to have more conclusive results.

- **Stroke patients - Tests and retests results**

To assess if there were any differences between the stroke patients' results, patients were asked to perform a second test. These potential differences were analyzed using the paired samples t-Test for all the studied parameters. It was noticed from the statistical test that, for mean and median values of muscle activation, no differences between both tests were detected, except for the median values in the Iliocostalis left, for the SEC* task, and in Multifidus left, for the RC* task.

Regarding the EMG frequencies, no significant differences were noticed for the SEO* and SEC* tasks, except for the Iliocostalis left muscle in peak, mean and median frequencies and the SEC* task.

Although stroke sample results were, in general, different from the ones obtained for the healthy population, when using the paired samples t-Test in test and retest results of stroke sample, no statistical differences were noticed for COP parameters and COP frequencies ($p\text{-value}>0.05$).

When observing the COP total area displacement individually, it is possible to understand and confirm test and retest similarities.

In general, from the analysis of COP and EMG results, it can be concluded that the test and retest data are very similar and the 10 stroke patients participating in this work had identical postural adjustments regarding themselves and while performing the same task.

* **SEO** = Standing with eyes open; **SEC** = Standing with eyes closed; **RFEO** = One leg stand (right leg), eyes open; **RFEC** = One leg stand (right leg), eyes closed; **LFEO** = One leg stand (left leg), eyes open; **LFEC** = One leg stand (left leg), eyes closed; **RR** = Reaching an object on the subject's right side, with his left hand; **RL** = Reaching an object on the subject's left side, with his right hand; **RC** = Reaching an object in front of the subject's dominant hand;

Chapter 7

7. Conclusions and future perspectives

To achieve the goals of this study, 43 healthy subjects and 10 stroke patients performed two tests in two different days. The protocol used for the healthy sample could not be performed by the stroke patients, considering that four of the nine tasks were too difficult for them– the tasks with only one foot on the platform. Therefore, only five tasks were used to make comparisons between populations, hence the increasing of the healthy database and the validation of its results were completed.

The data was processed, and the EMG data was correlated with the results from the posturography, so that some conclusions could be taken.

Regarding the healthy sample and their muscle activation results, it was noticed the Rectus Abdominis had similar values for every task, which indicated that, to maintain an upright stable posture, this group of muscles has an essential role. The External Obliques presented the higher values of muscle activation, however for the stroke patients the same was not detected.

When comparing both groups, it was possible to understand that the stroke patients had the higher values of activation. These observed values were for the Rectus Abdominis and the posterior trunk muscles, especially on the right side. The higher values on the right side suggested that the patients had a significant muscle tone and it was concordant with the sample studied, once nine of the patients had right hemiparesis.

It would be interesting to develop further studies concerning the posterior trunk muscles of the stroke patients, since they presented very high values of muscle activation when compared to the healthy sample.

A larger COP amplitude and higher mean and median values of muscle activation were spotted in the task with no visual information, for the stroke patients. These results were closely related to the ones observed in healthy subject. However, for the task with the eyes open, no similarities between populations were detected for the COP amplitude in the y direction. The healthy values obtained for this parameter were not expected once this task had visual information and both feet stood on the platform.

Concerning the healthy sample results, for tasks with one foot on the platform and no visual information, body sway was intensified. Stroke patients could not perform these tasks, so the comparison was not possible.

Comparing both samples, the results obtained were different in almost every parameter and task. However, the paired samples t-Test was applied in both populations' results. This statistical test was used to analyze the reliability of the tests results, in a healthy sample, and to help understanding if there were any differences between the two tests performed by the stroke group. After this analysis, no significant differences between results from test and retest were detected for the healthy sample and the stroke group. Therefore, it was a very important step, especially for the healthy data, which indicated that the results were reliable, and they can be used in future studies and in a clinical context.

With the aim of better understanding the postural control system and postural control impairments associated with this pathology, new parameters could be added and evaluated. Furthermore, a couple of improvements could also be done in the protocol and in the equipment used.

The healthy sample had 43 subjects, but the mean age was 26.6 years with a standard deviation of 9.80 years, which is quite different from the mean age of the stroke sample, rounding the 55.7 years of age, and with a standard deviation of 11.7 years. Concluding that the stroke sample is very much older and, consequently, this may have influenced the results, since aging influences the postural control. In future studies, it would be important to add some older subjects to the healthy database.

Throughout the test's performance, the healthy subjects moved their feet muscles and their positioning, thus it was thought to mark an area on the platform to place the feet at the beginning of each task.

In addition, it could be recorded the muscular reaction of each patient's feet throughout all protocol. If all subjects began from the same area and, at the same time, an analysis of the COP parameters could be added to the analysis of the muscle activation values, the results were expected to be more assertive and correct.

Another interesting suggestion would be to analyze the time of the muscle activation and the corresponding time of the COP displacement response, especially in the stroke patients. Thus, in order to preserve a stable posture, it would be possible to detect the problems in muscle activation individually and their improvement during the patient's acquisition.

Meanwhile, stroke patients could not perform the 9 tasks protocol, especially the ones with only one foot on the platform. To guarantee the safety of the patients, only 5 tasks were performed, which may have limited some of this study's findings.

Regarding these patients' well-being, the MVC tests had to suffer some modifications, since they could not execute the specific required movements to record the posterior trunk muscle activation. Instead, patients were asked to sit on the marquise and produce a force backwards, which turned out to be safer for them to carry out. This modification could cause some abnormal values and this fact may have influenced the final results.

In order to study the posterior trunk muscles and their activation, it would be interesting to add to the protocol a few tasks more directed to these muscles' activity and to these patients' conditions. Moreover, the sample size could also include more patients, with different diagnoses.

In this way, the protocol performed by both populations should be the same. The tasks, such as reaching an object, may be discarded since they haven't brought constructive results for this study.

Concerning the EMG equipment, some impairments during the acquisitions were witnessed. Some of the subjects participating in this work may have sweated and moved abruptly, causing the electrodes disconnection and their incorrect positioning. These circumstances have an influence in the EMG records. Additionally, it was considered that a band in an elastic tissue could be developed. This band would be wrapped around the trunk, fixing the electrodes and improving the problems felt with the incorrect positioning and disconnection.

One can concluded, as for this work and its results, that not only the main goals were achieved, but also these results may contribute for clinical and scientific context.

The present study helped in the validation of the previous results obtained, and now there is a reliable healthy database available to help in later studies. Besides, concerning their trunk muscles activation and the displacement of their COP, the postural adjustments of the stroke patients were analyzed and identified, given more information for the postural control assessments.

Although in the future a lot of work can be developed, it is expected that, with all these postural control studies, the rehabilitation area will have many tools and information capable of helping stroke patients individually and in a more personalized way.

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A

Appendix A

Consentimento Informado

Caro (a) Senhor (a),

O meu nome é Emanuela Teixeira do Departamento de Física e realizo o mestrado integrado em Engenharia Biomédica na Faculdade de Ciências e Tecnologia na Universidade Nova de Lisboa. Gostaria de pedir a sua colaboração para a concretização de um estudo de investigação sob o tema "Desenvolvimento de base normativa em patologias do foro neurológico baseado em posturografia e eletromiografia". Também gostaria de informar que para a realização deste projeto será necessário a recolha de imagens da secção em estudo, o tronco.

A recolha de dados será realizada na FCT-UNL, recorrendo ao equipamento *Biosignalsplux Kit/Plataforma de forças*.

Em qualquer momento do estudo é livre de desistir, se assim o pretender. Ao longo de todo este processo não terá despesas nem receberá nada em troca, visto que a sua participação é voluntária.

É de salientar que, com a sua colaboração, estará não só a contribuir para a realização deste projeto de investigação, mas também para um maior conhecimento na área científica, promovendo o desenvolvimento de novas metodologias de prevenção e diagnóstico de alterações da postura, que poderão beneficiar a sociedade no futuro.

Todos os dados recolhidos serão anónimos e confidenciais e não serão publicadas quaisquer fotografias que permitam a sua identificação.

Se existirem dúvidas no preenchimento correto deste questionário, por favor contacte a Emanuela Teixeira através do contacto telefónico 918472826, ou email ec.teixeira@campus.fct.unl.pt

Confirmo que expliquei à pessoa abaixo indicada, de forma adequada e inteligível, os procedimentos necessários ao ato referido neste documento. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada da decisão.

(Assinatura legível)____

Data: …../…../….

Ao Participante

Por favor, leia com atenção todo o conteúdo deste documento. Não hesite em solicitar mais informações se não estiver completamente esclarecido(a). Verifique se todas as informações estão corretas. Se tudo estiver conforme, então, assine este documento.

Declaro ter compreendido os objetivos que me foram propostos e explicados. Foi-me concedida a oportunidade de esclarecer todas as dúvidas sobre o assunto e para todas elas obtive uma resposta esclarecedora. Tive tempo suficiente para refletir sobre esta proposta, pelo que declaro que autorizo/Não autorizo (riscar o que não interessa) o ato indicado, bem como os procedimentos diretamente relacionados que sejam necessários no meu próprio interesse e justificados por razões fundamentadas.

(Assinatura legível) ____

Data: …../…../…..

Questionário de Caraterização da Amostra

O presente questionário tem como principal objetivo recolher informações para caraterizar a amostra de um estudo científico. Este estudo visa a definir o padrão da postura ereta. Os dados recolhidos são anónimos e serão usados exclusivamente para a caraterização da amostra no presente estudo.

Código: _______ (não preencher este campo)

1. Idade: __________ anos

2. Sexo: □ Masculino □ Feminino

3. Altura: __________ m

4. Peso: ___________ kg

5. Nacionalidade:

□ Portuguesa

□ Outra Qual?________________________________

6. Habilitações literárias: __________________________

7. Profissão:______________________________________

8. Estado Civil: ___________________________________

9. Mão dominante:_________________________________

10. Prática de atividade física: □ Sim □ Não

11. Caso tenha respondido sim na questão anterior:

Com que frequência:

□ Entre 1 a 3 dias por semana □ Mais do que 3 dias por semana

B

Appendix B

Consentimento Informado

Caro (a) Senhor (a),

O meu nome é Emanuela Teixeira do Departamento de Física e realizo o mestrado integrado em Engenharia Biomédica na Faculdade de Ciências e Tecnologia na Universidade Nova de Lisboa. Gostaria de pedir a sua colaboração para a concretização de um estudo de investigação sob o tema “Desenvolvimento de base normativa em patologias do foro neurológico baseado em posturografia e eletromiografia”. Também gostaria de informar que para a realização deste projeto será necessário a recolha de imagens da secção em estudo, o tronco.

A recolha de dados será realizada no Centro de Medicina e Reabilitação de Alcoitão, recorrendo ao equipamento *Biosignalsplux Kit/Plataforma de forças*.

Em qualquer momento do estudo é livre de desistir, se assim o pretender. Ao longo de todo este processo não terá despesas nem receberá nada em troca, visto que a sua participação é voluntária.
É de salientar que, com a sua colaboração, estará não só a contribuir para a realização deste projeto de investigação, mas também para um maior conhecimento na área científica, promovendo o desenvolvimento de novas metodologias de prevenção e diagnóstico de alterações da postura, que poderão beneficiar a sociedade no futuro.

Todos os dados recolhidos serão anónimos e confidenciais e não serão publicadas quaisquer fotografias que permitam a sua identificação.

Se existirem dúvidas no preenchimento correto deste questionário, por favor contacte a Emanuela Teixeira através do contacto telefónico 918472826, ou email ec.teixeira@campus.fct.unl.pt

Confirmo que expliquei à pessoa abaixo indicada, de forma adequada e inteligível, os procedimentos necessários ao ato referido neste documento. Respondi a todas as questões que me foram colocadas e assegurei-me de que houve um período de reflexão suficiente para a tomada da decisão.

(Assinatura legível)____
Data: …../…../….

Ao Participante

Por favor, leia com atenção todo o conteúdo deste documento. Não hesite em solicitar mais informações se não estiver completamente esclarecido(a). Verifique se todas as informações estão corretas. Se tudo estiver conforme, então, assine este documento.

Declaro ter compreendido os objetivos que me foram propostos e explicados. Foi-me concedida a oportunidade de esclarecer todas as dúvidas sobre o assunto e para todas elas obtive uma resposta esclarecedora. Tive tempo suficiente para refletir sobre esta proposta, pelo que declaro que autorizo/Não autorizo (riscar o que não interessa) o ato indicado, bem como os procedimentos diretamente relacionados que sejam necessários no meu próprio interesse e justificados por razões fundamentadas.

(Assinatura legível) ____
Data: …../…../…..

Questionário de Caraterização da Amostra

O presente questionário tem como principal objetivo recolher informações para caraterizar a amostra de um estudo científico. Este estudo visa a definir o padrão da postura ereta. Os dados recolhidos são anónimos e serão usados exclusivamente para a caraterização da amostra no presente estudo.

Código: _______ (não preencher este campo)

1. Idade: ___________ anos

2. Sexo: □ Masculino □ Feminino

3. Altura: ___________ m

4. Peso: ____________ kg

5. Nacionalidade:
   □ Portuguesa

   □ Outra Qual?__________________________________

6. Habilitações literárias: ___________________________

7. Profissão:____

8. Estado Civil: _____________________________________

9. Mão dominante:___________________________________

10. Diagnóstico clínico:____________________________________

11. Data Atual:__________________________

12. Data do início do tratamento:_______________________

13. Tempo decorrido desde o AVC:_________________________

14. Classificação da Espasticidade: (Escala de Ashworth modificada)
□ 0 (Sem aumento do tónus muscular)
□ 1 (Pequeno aumento do tónus muscular com mínima resistência no fim do movimento)
□ 1+ (Leve aumento do tónus muscular com mínima resistência em menos de metade do movimento)
□ 2 (Aumento do tónus muscular na maior parte do movimento, mas a mobilização passiva é efetuada com facilidade)
□ 3 (Aumento mais acentuado do tónus muscular, mas a movimentação passiva é efetuada com dificuldade)
□ 4 (Segmento afetado rígido em flexão ou extensão)

15. Regime de tratamento: □ Internamento □ Ambulatório

16. Caso tenha respondido na questão anterior "Ambulatório":
Com que frequência:
□ Entre 1 a 3 dias por semana □ Mais do que 3 dias por semana

C

Appendix C

Force Platform
Data Sheet

Force Platform 02032017

SPECIFICATIONS

> **Axis:** 1(Z)
> **Sensitivity:** ±0.05%
> **Gain:** 491.605
> **Consumption:** 56 μA (per cell)
> **Range:** up to 800 kgf (200 kgf per cell)
> **Construction:** Aluminum

FEATURES

> 4 independent steel load cells
> 360° protractor drawn on the top face
> Increased resistance to deformations
> Adjustable feet for manual leveling
> High-performance feet design
> Equidistant load cells (diagonally placed)
> Separate signal conditioning per load cell for better signal-to-noise ratio

APPLICATIONS

> Center of gravity assessment
> Biomedical research
> Physiotherapy
> Biomechanics
> Rehabilitation research
> Sports Research

GENERAL DESCRIPTION

Center of gravity distribution, jump analysis, weight assessment and force production capacity, are just some of the applications where force assessment is important. Our robust yet lightweight 1D force platform enables uncompromised data acquisition both in lab and field measurements.

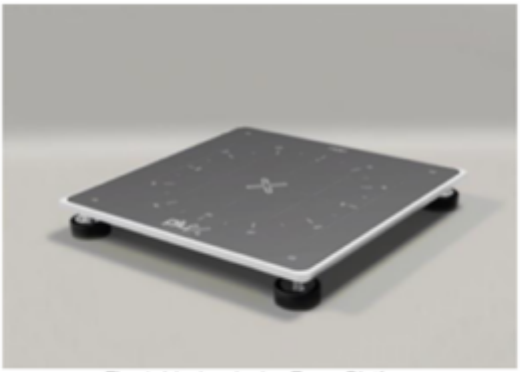


Fig. 1. biosignalsplux Force Platform.

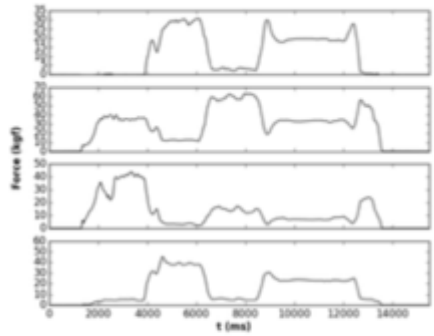


Fig. 2. Typical force platform output with one channel per load cell (acquired with OpenSignals)

Fig. 3. Top face protractor installed on the Force Platform.

biosignalsplux
wearable body sensing platform

PLUX – Wireless Biosignals, S.A.
Av. 5 de Outubro, n. 70 – 8.
1050-059 Lisbon, Portugal
plux@plux.info
http://biosignalsplux.com/

REV A

biosignalsplux Force Platform Data Sheet

TRANSFER FUNCTION

[0 kgf, 200 kgf][1]

$$Weight\ (kgf) = \frac{ADC\ .\ C}{V_{FS}\ .(2^{nbits} - 1)}$$

$$C = 406.831\ kg.mV/V$$

V_{FS} – Output voltage in mV/V @ 200kgf (factory calibrated value specific to each cell)
ADC – Value sampled from the channel
$nbits$ – Number of bits of the channel[2]

CENTER OF PRESSURE

[[-225, 225] mm, [-225, 225] mm]

$$CoPx\ (mm) = \frac{W}{2} \cdot \frac{C2 + C3 - C1 - C4}{C2 + C3 + C4 + C1}$$

$$CoPy\ (mm) = \frac{L}{2} \times \frac{C2 + C1 - C3 - C4}{C2 + C3 + C4 + C1}$$

If $C2 + C3 + C4 + C1 = 0$
then $CoPx = 0$ and $CoPy = 0$

W = 450 mm (platform width)
L = 450 mm (platform length)
$C1$ – Weight (in kgf) on the channel with the cable marked in blue
$C2$ – Weight (in kgf) on the channel with the cable marked in black
$C3$ – Weight (in kgf) on the channel with the cable marked in yellow
$C4$ – Weight (in kgf) on the channel with the cable marked in red

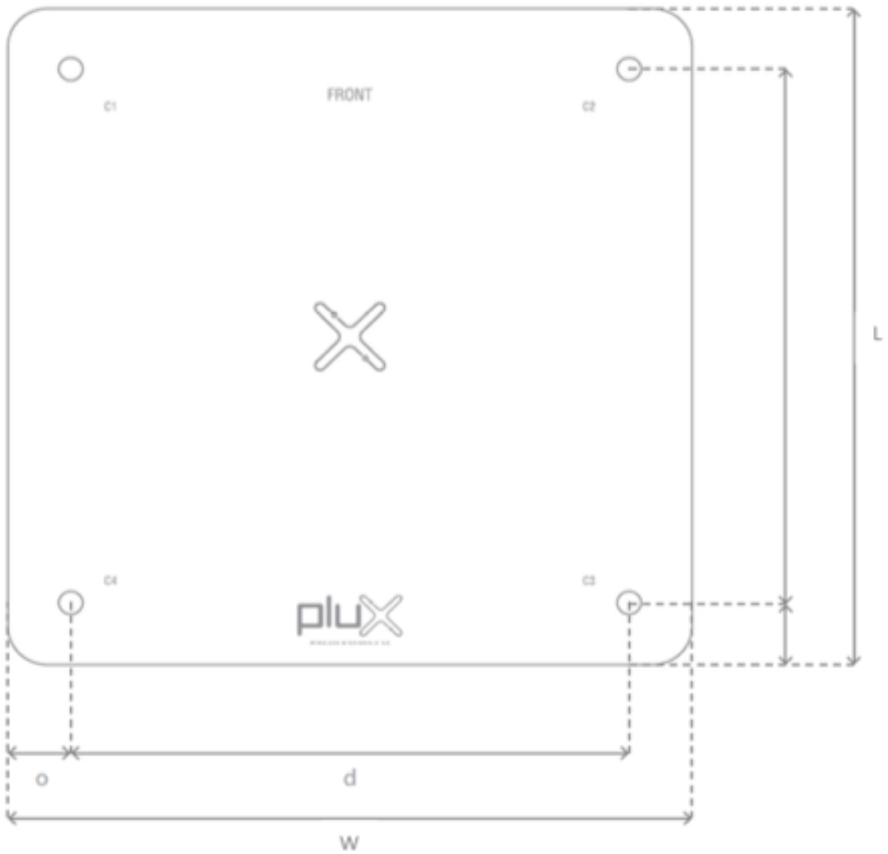
[1] Per cell.

[2] The number of bits for each channel depends on the resolution of the Analog-to-Digital Converter (ADC); in biosignalsplux the default is 16-bit resolution ($n = 16$), although 12-bit ($n = 12$) and 8-bit ($n = 8$) may also be found.

biosignalsplux Force Platform Data Sheet

PHYSICAL CHARACTERISTICS

> **W x L:** 45x45 cm
> **Max Height (recommended):** 6.7 cm
> **Min Height:** 5.8 cm
> **Min Height (using the optional feet):** 4 cm
> **Total Weight**: 9 kg



ORDERING GUIDE

Reference	Package Description
SENSADV-FORPLAT1	Sturdy unidimensional platform with four independent load cells for jump, leg press, and similar setups.
BIOKITFSR1	Sturdy unidimensional platform with four independent load cells for jump, leg press, and similar setups, bundled with a wireless 4-channel hub for real-time wireless data acquisition and display or logging into an internal memory card.

Appendix D

In this appendix it will be presented the analysis of mean and median values from EMG arrays for each muscle, along the nine tasks, for a group of healthy subjects.

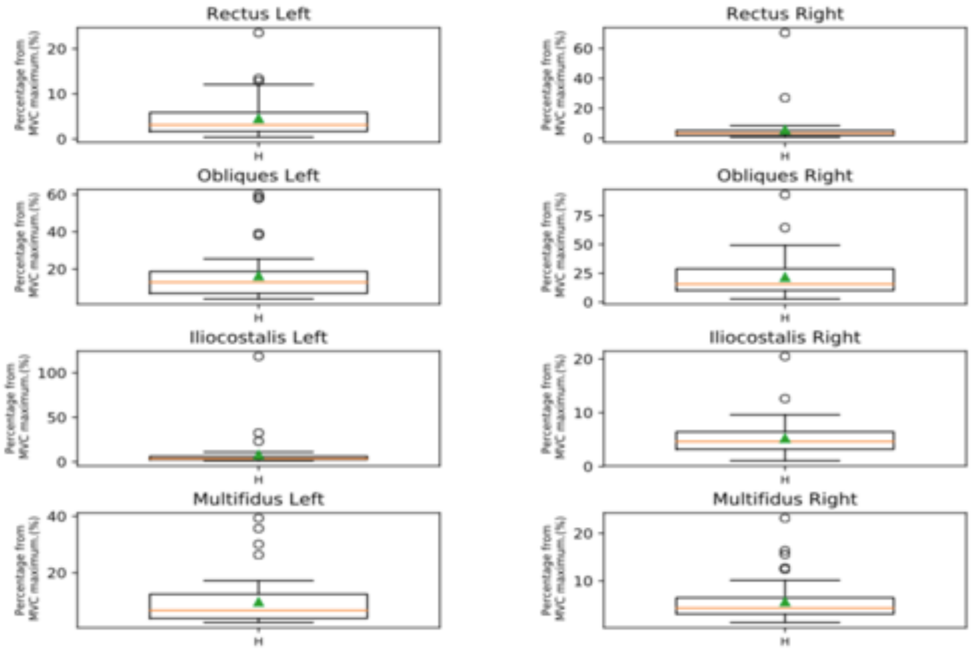


Figure D.1 – Mean values for the task LFEO, for each muscle.

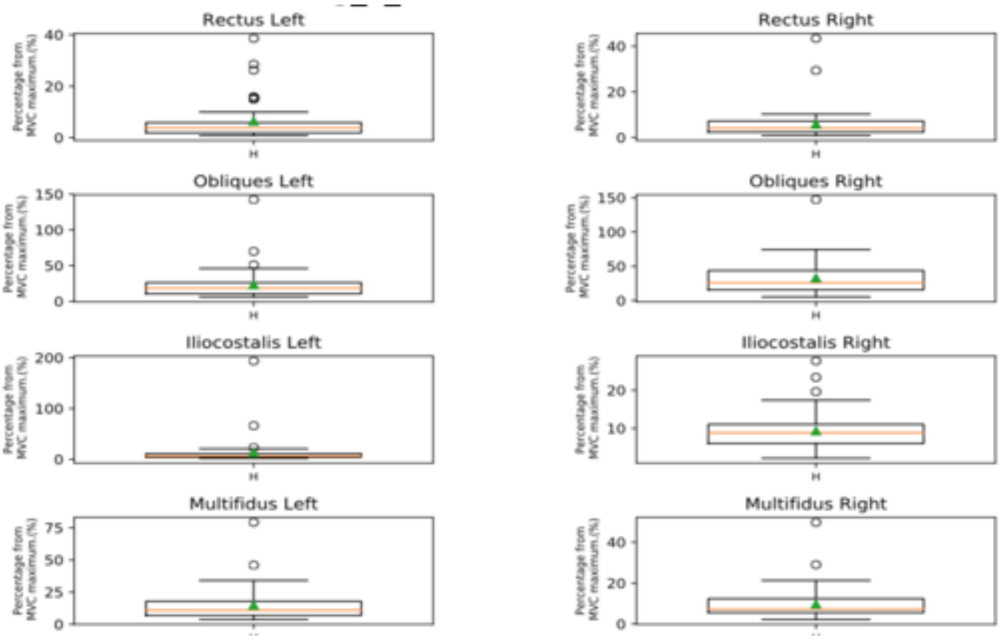


Figure D.2 – Mean values for the task LFEC, for each muscle.

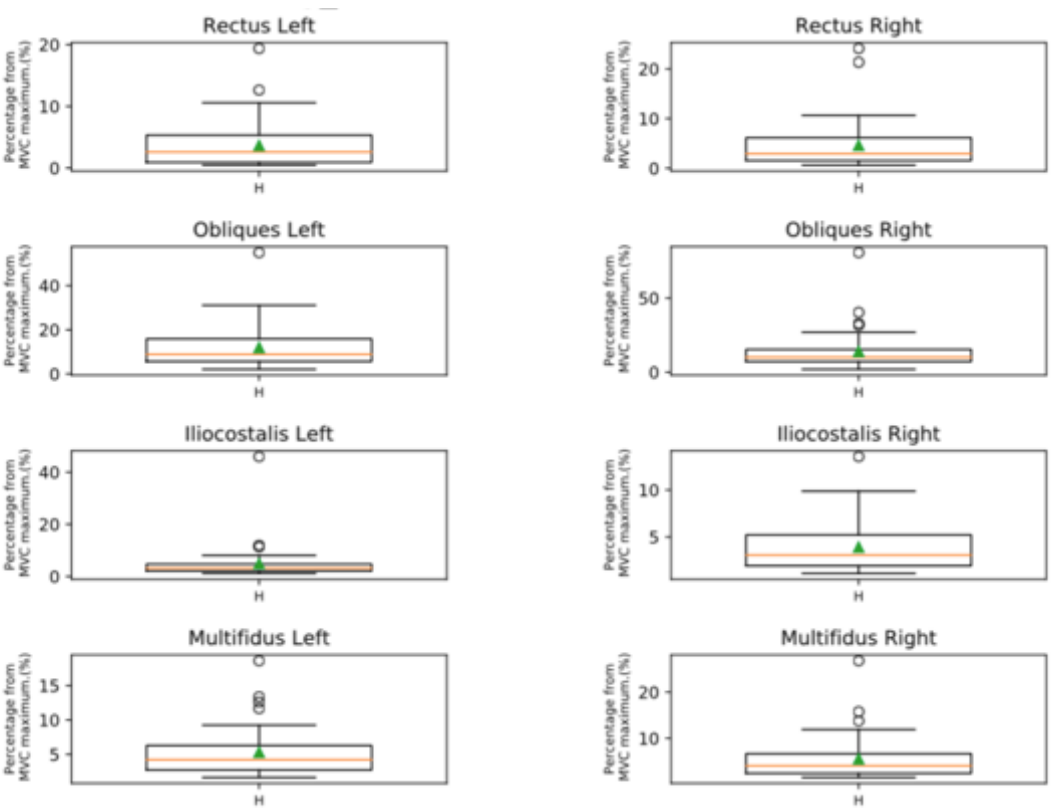


Figure D.3 – Mean values for the task SEC, for each muscle.

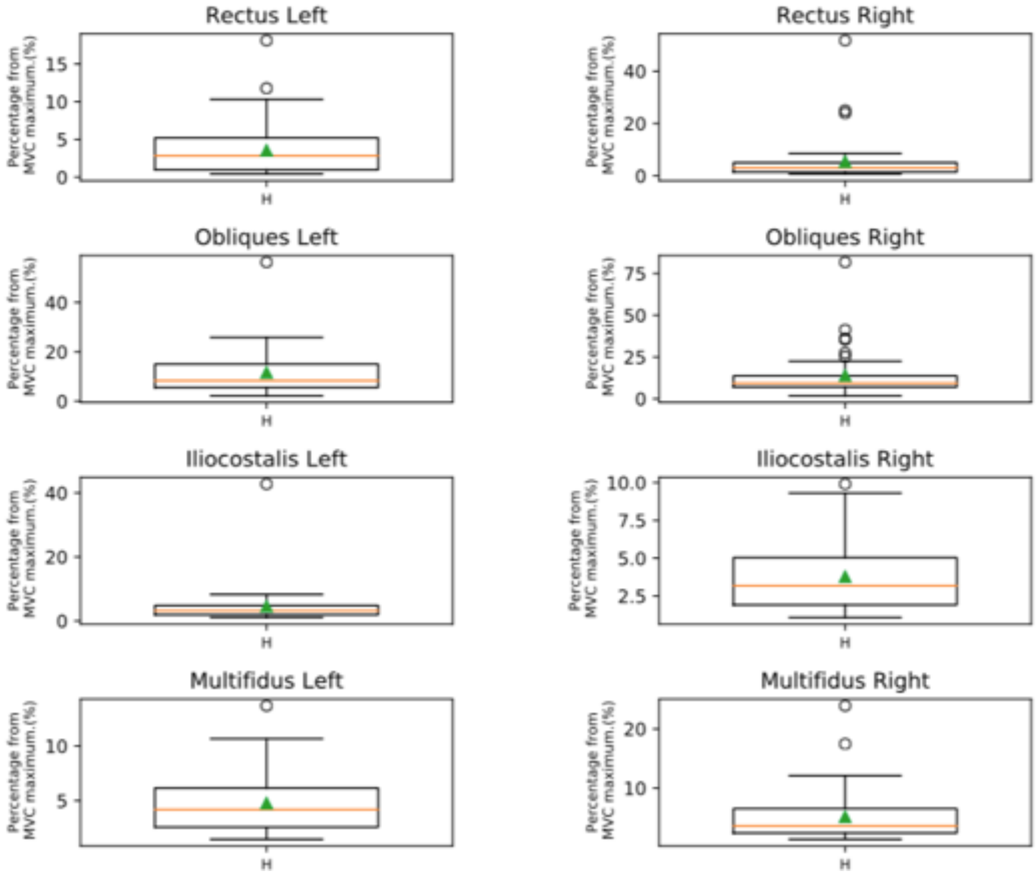


Figure D.4 – Mean values for the task SEO, for each muscle.

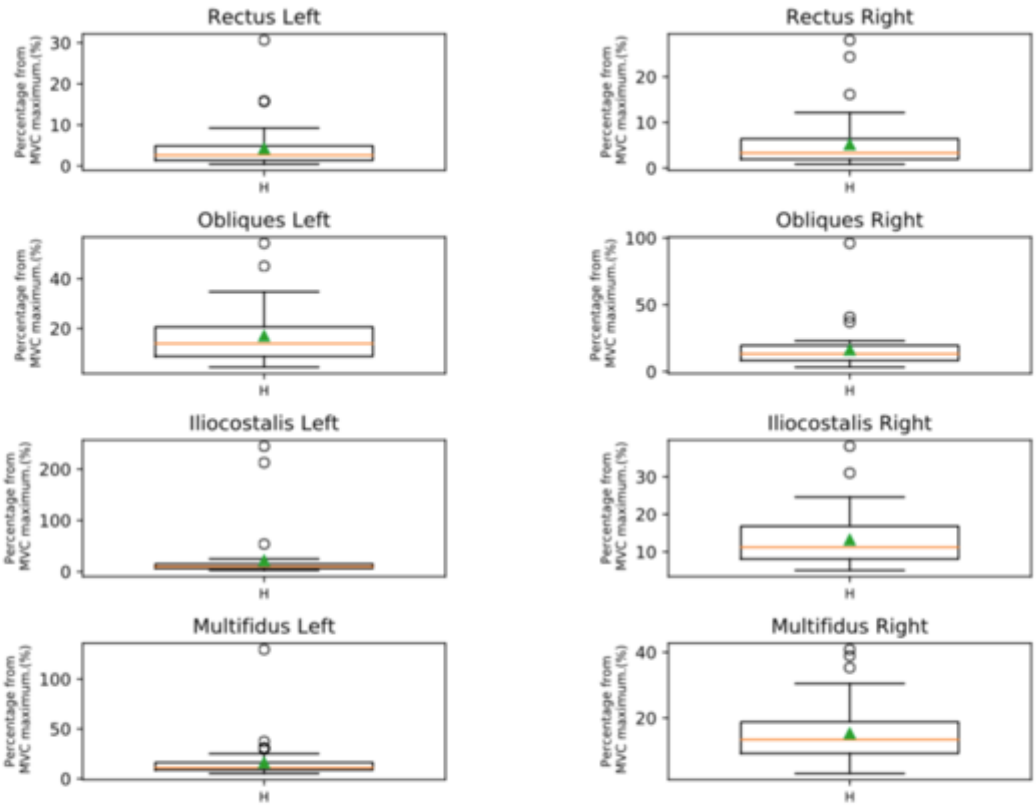


Figure D.5 – Mean values for the task RL, for each muscle.

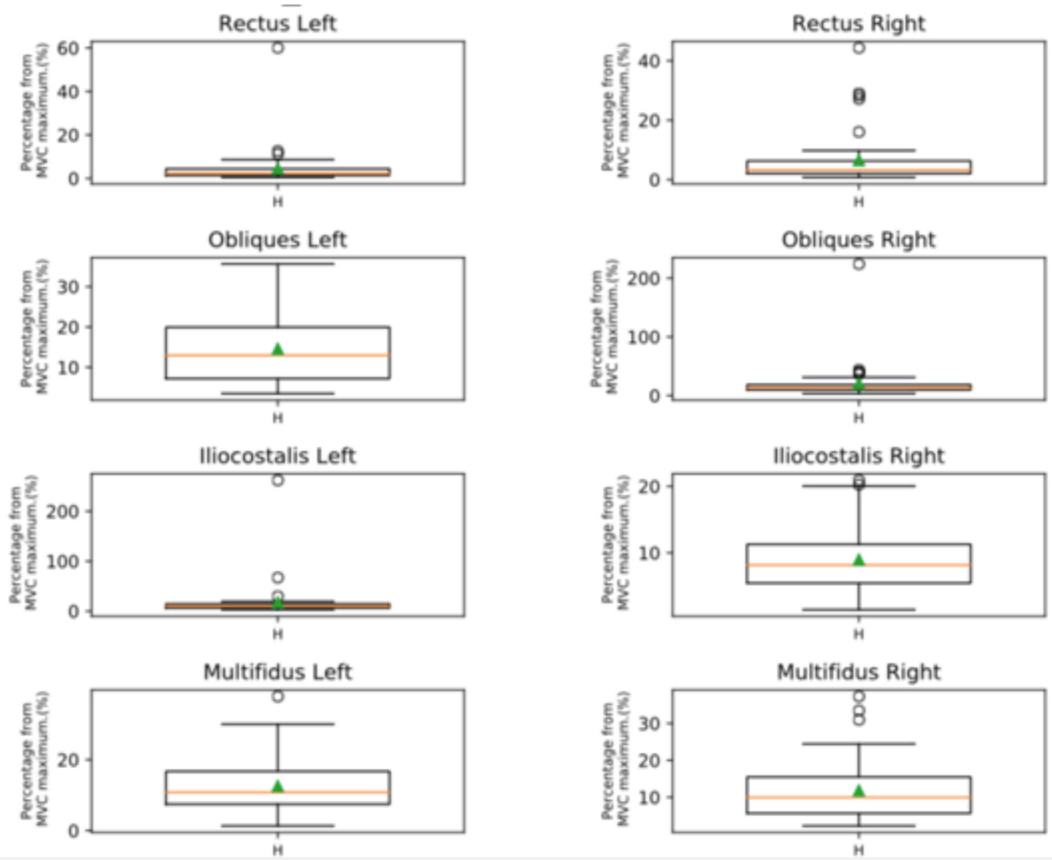


Figure D.6 – Mean values for the task RC, for each muscle.

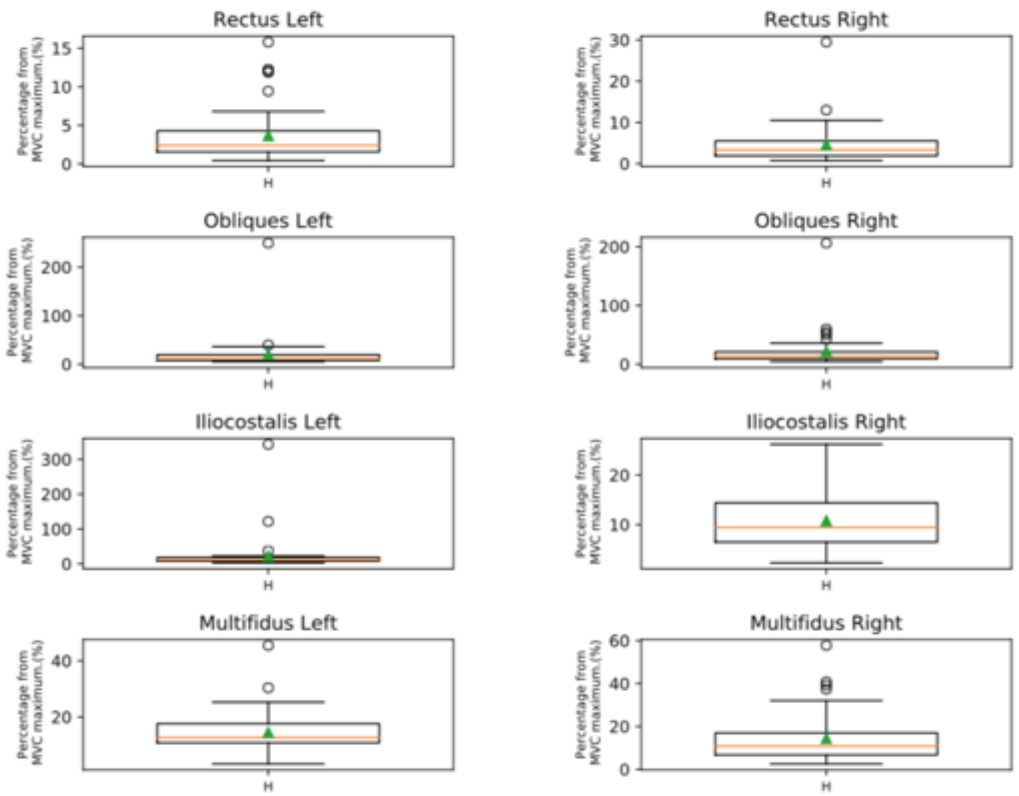


Figure D.7 – Mean values for the task RR, for each muscle.

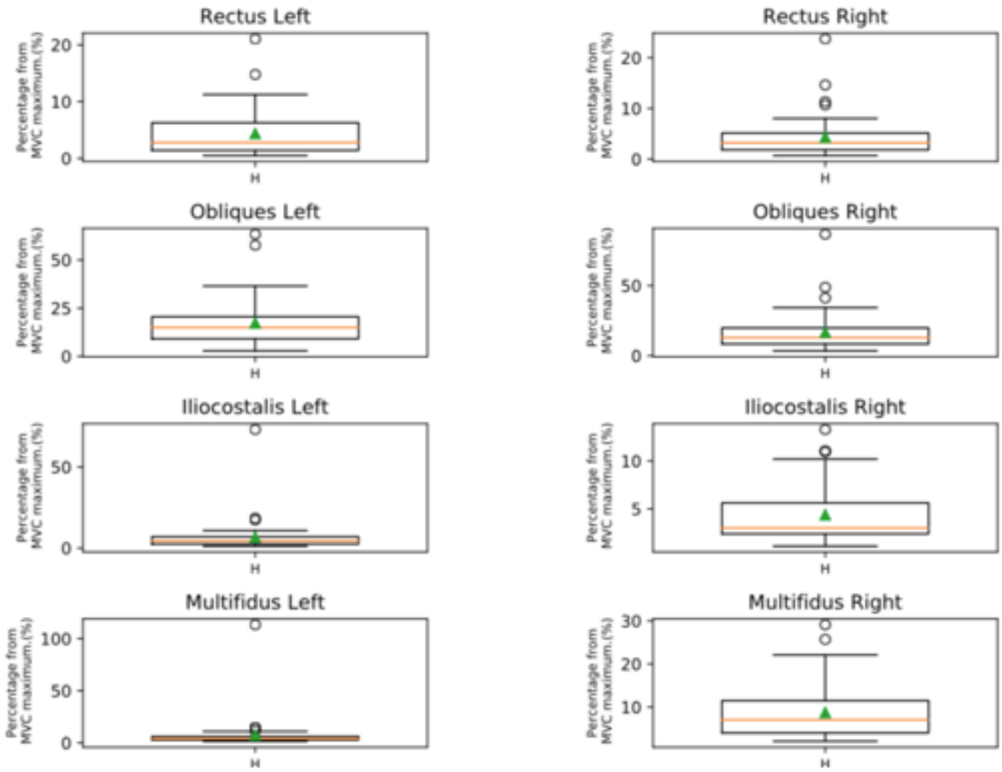


Figure D.8 – Mean values for the task RFEO, for each muscle.

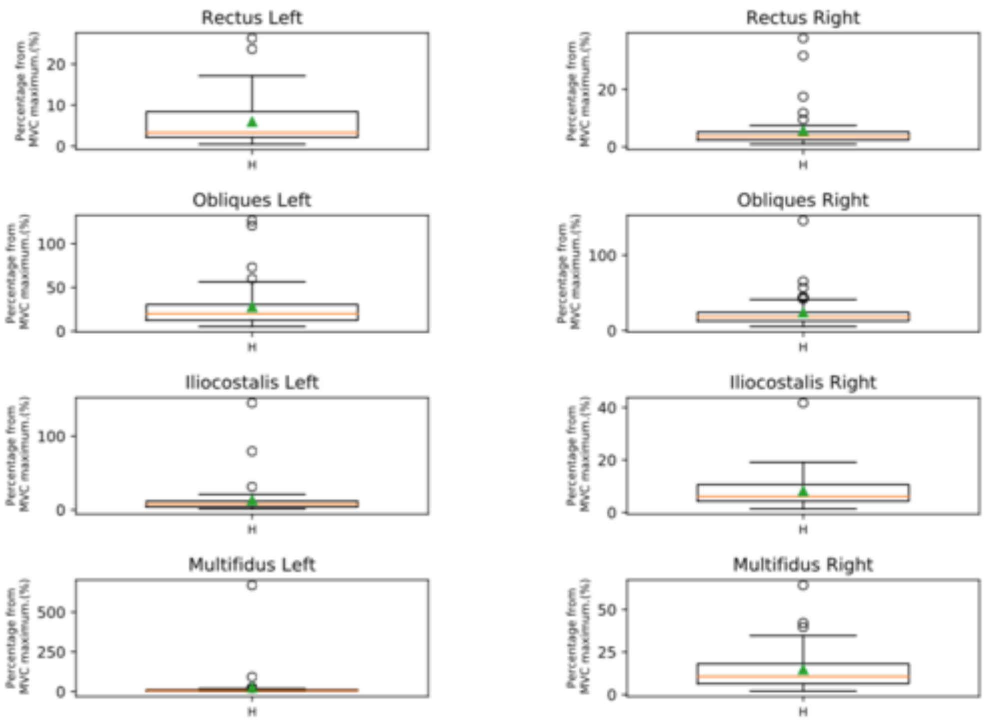


Figure D.9 – Mean values for the task RFEC, for each muscle.

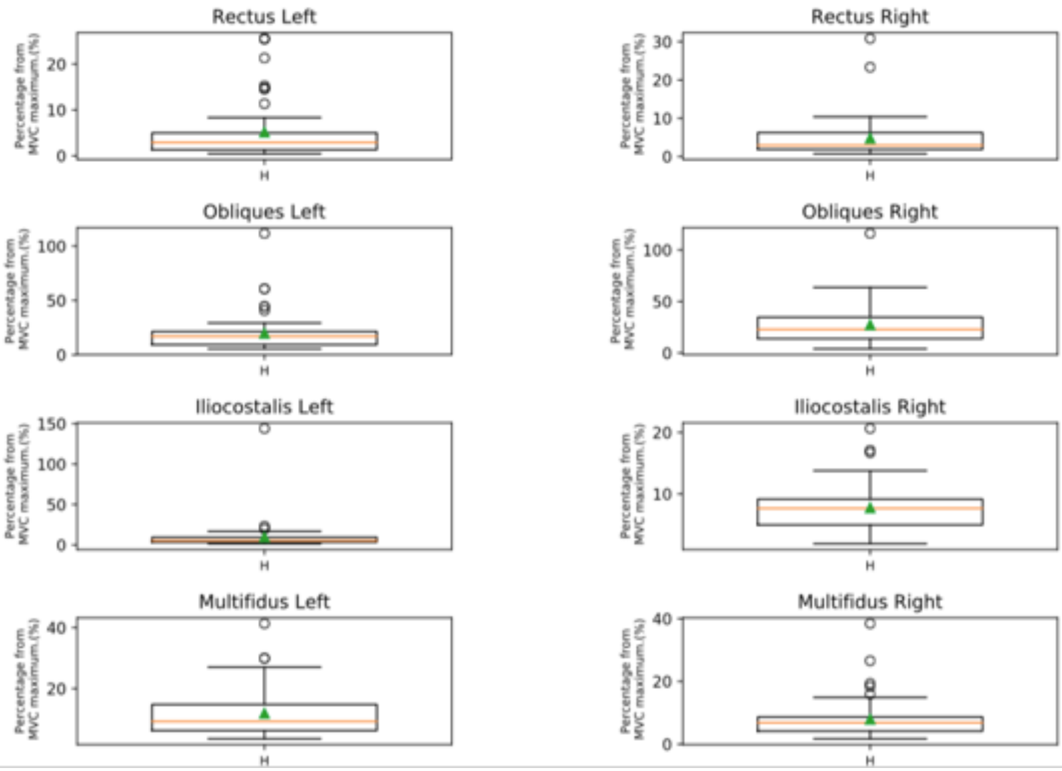


Figure D.10 – Median values for the task LEFC, for each muscle.

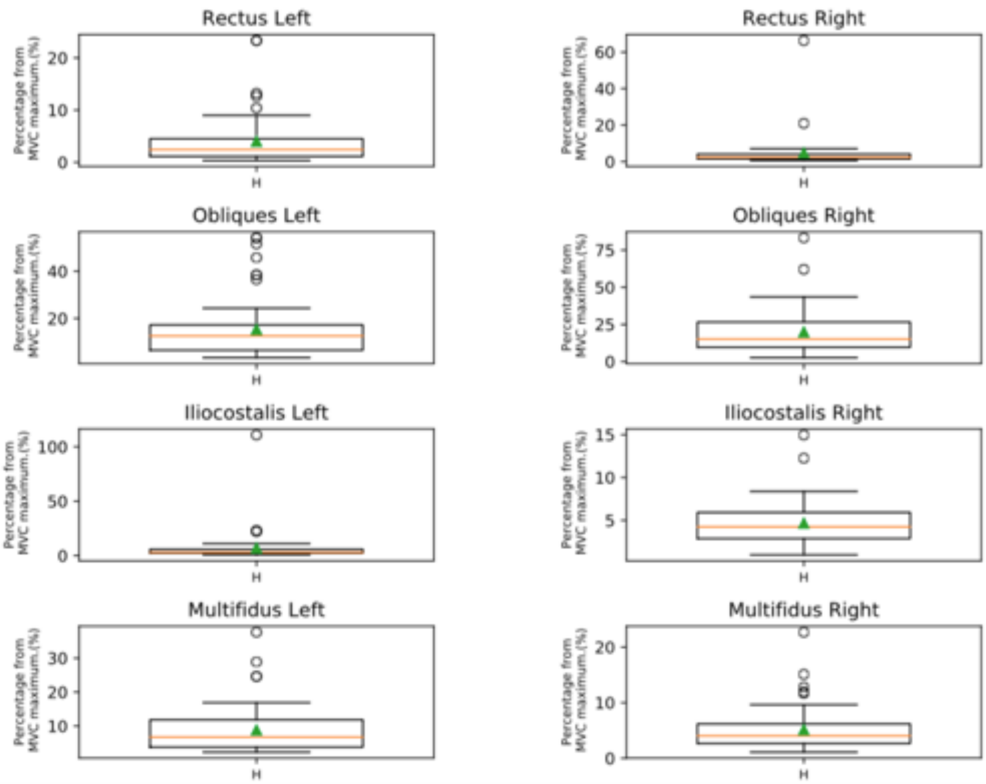


Figure D.11 – Median values for the task LEFO, for each muscle.

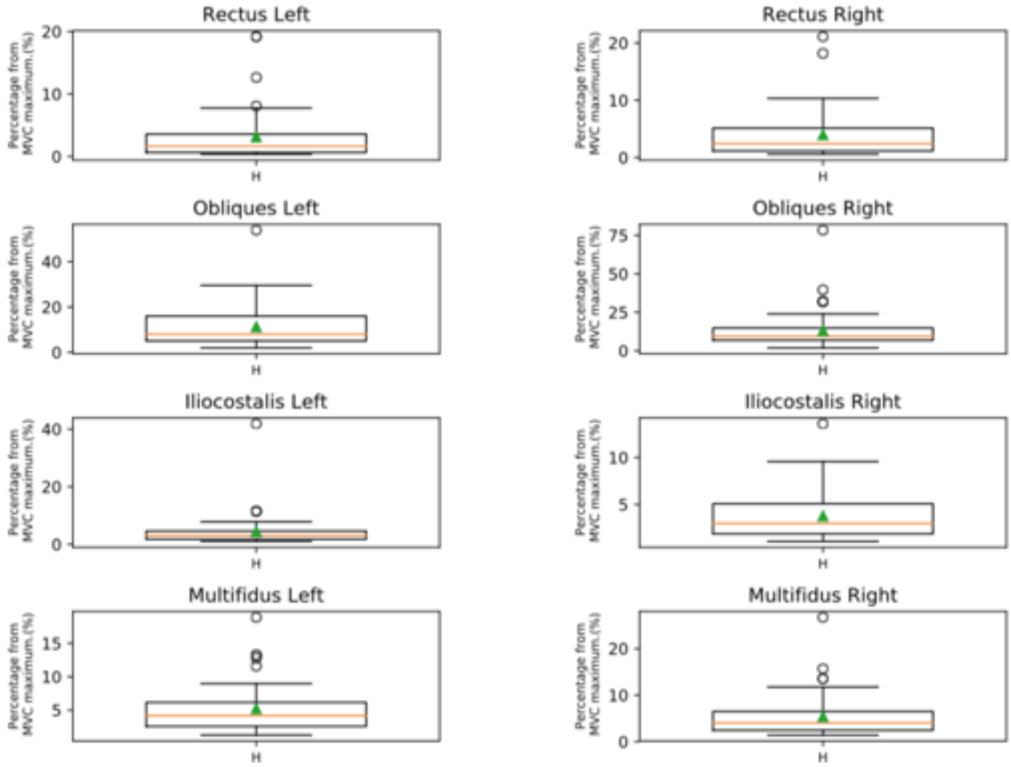


Figure D.12 – Median values for the task SEC, for each muscle.

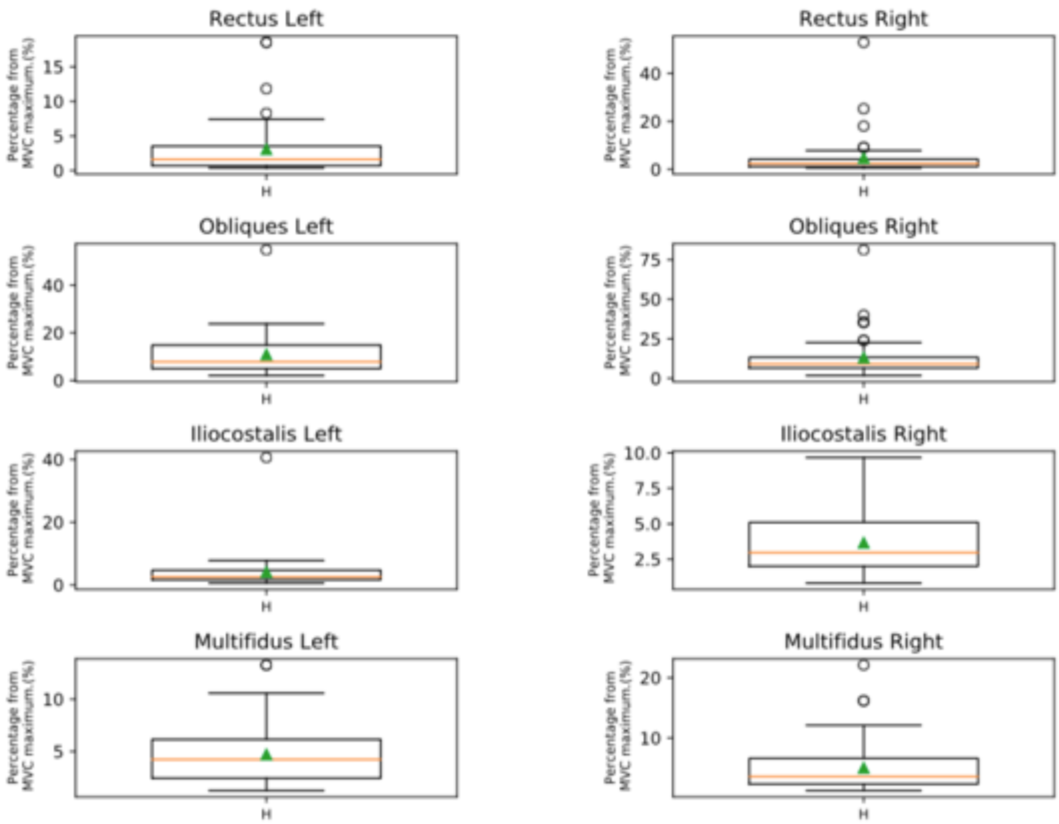


Figure D.13 – Median values for the task SEO, for each muscle.

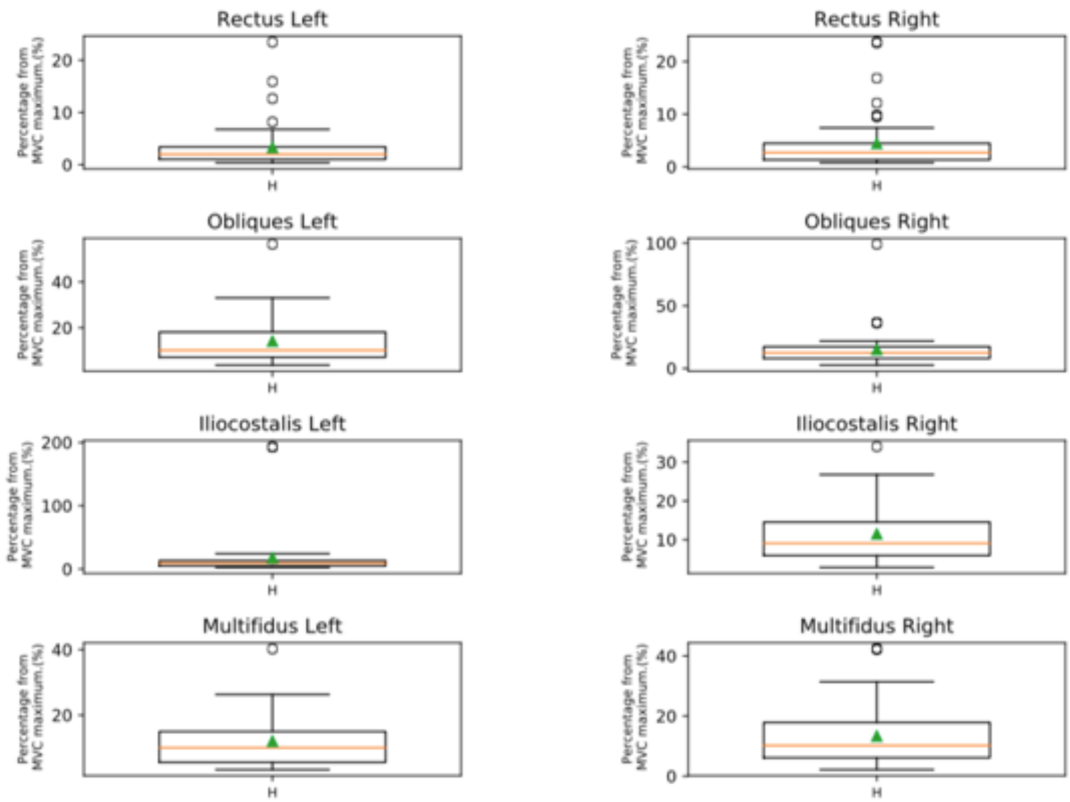


Figure D.14 – Median values for the task RL, for each muscle.

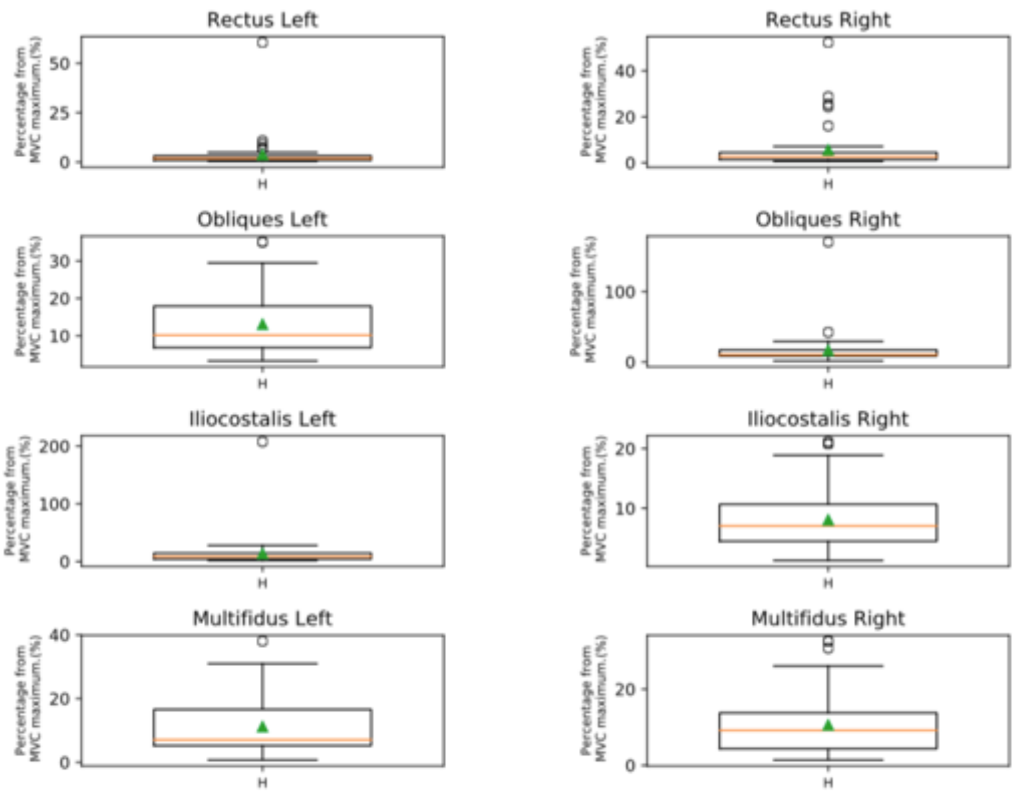


Figure D.15 – Median values for the task RC, for each muscle.

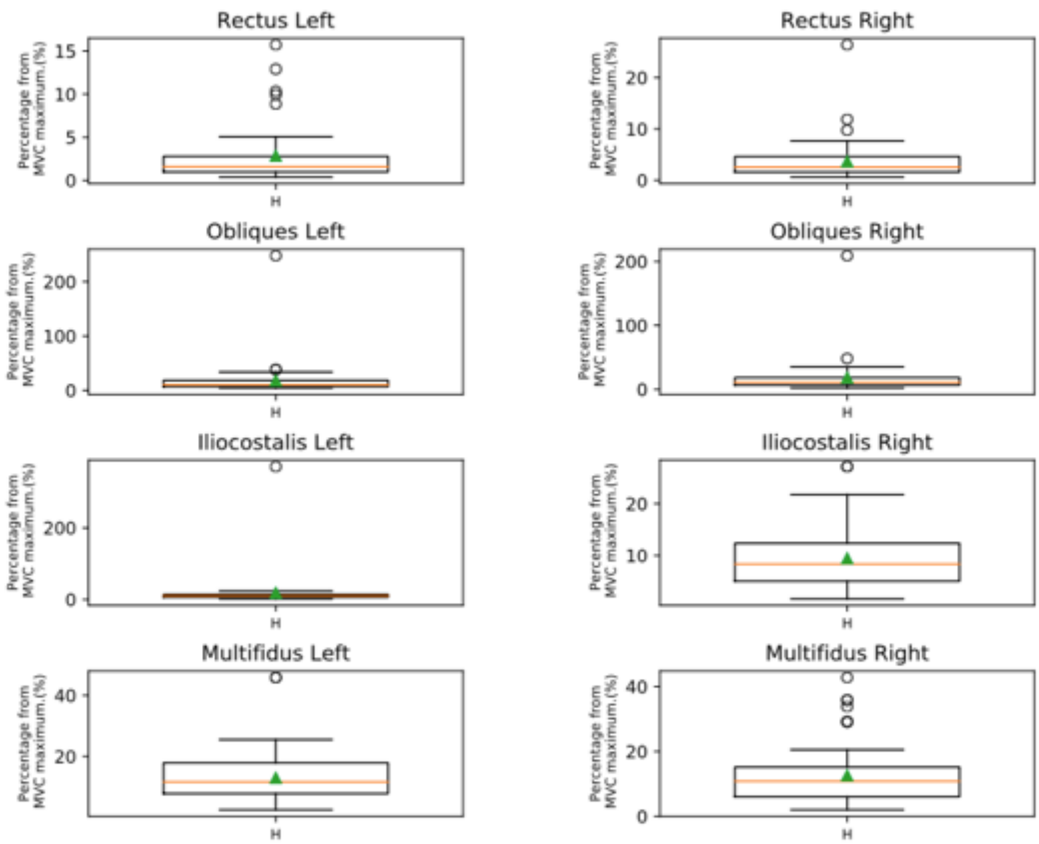


Figure D.16 – Median values for the task RR, for each muscle.

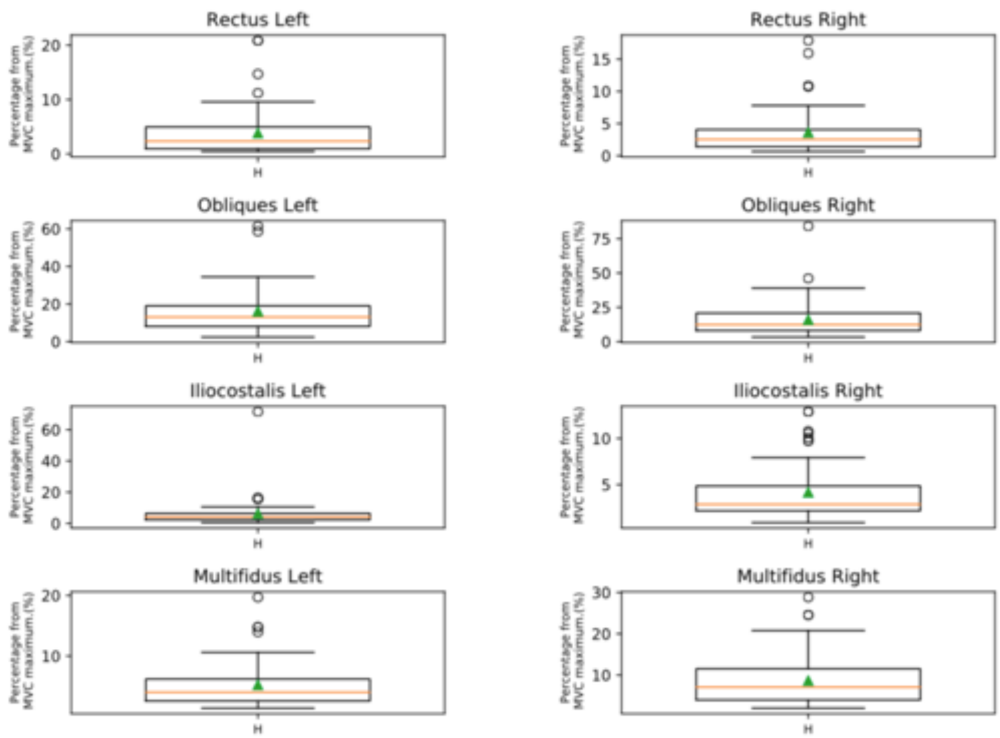


Figure D.17 – Median values for the task RFEO, for each muscle.

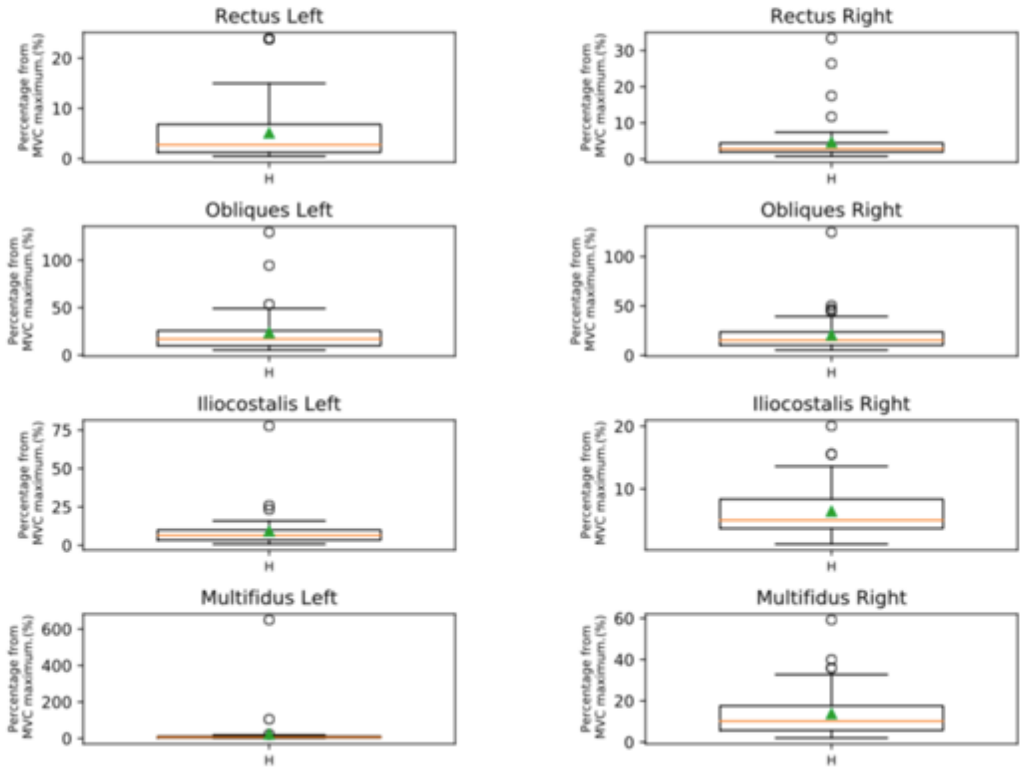
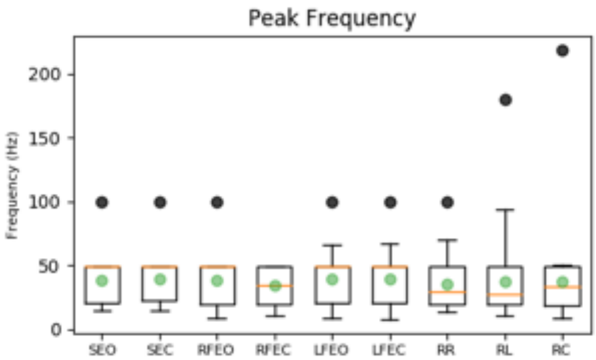


Figure D.18 – Median values for the task RFEC, for each muscle.

E

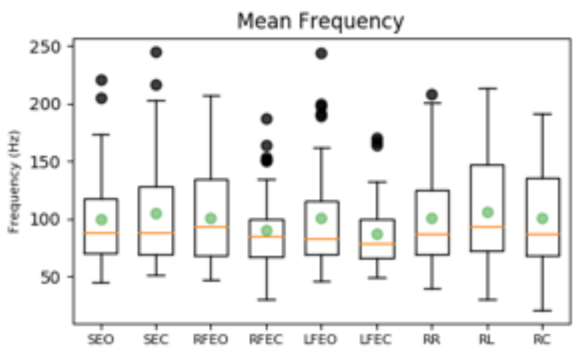
Appendix E

Now it will be presented the analysis of EMG frequency for each muscle, along the nine tasks and for each frequency studied, for a sample of healthy subjects.



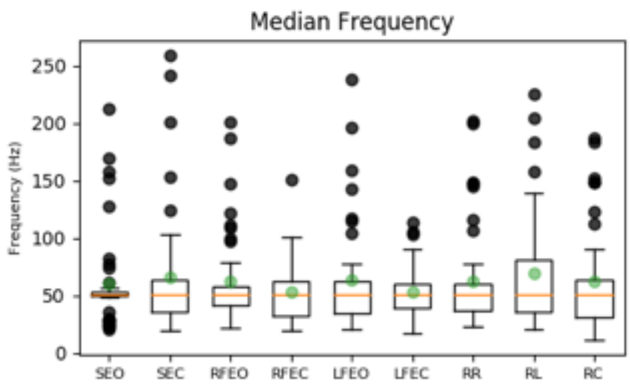
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0512	-							
RFEO	0.3241	0.1611	-						
RFEC	0.2985	0.0541	0.1656	-					
LFEO	0.3519	0.8366	0.1158	0.0863	-				
LFEC	0.1221	0.7807	0.2649	0.1859	0.7496	-			
RR	0.0457	0.0009	0.0408	0.6566	0.0109	0.0118	-		
RL	0.5310	0.1803	0.8840	0.4657	0.3033	0.0883	0.8582	-	
RC	0.0510	0.0020	0.1062	0.4711	0.0447	0.0442	0.4247	0.7626	-

Figure E.1 – Boxplot graphic and p-values between tasks, for peak frequency of RaR.



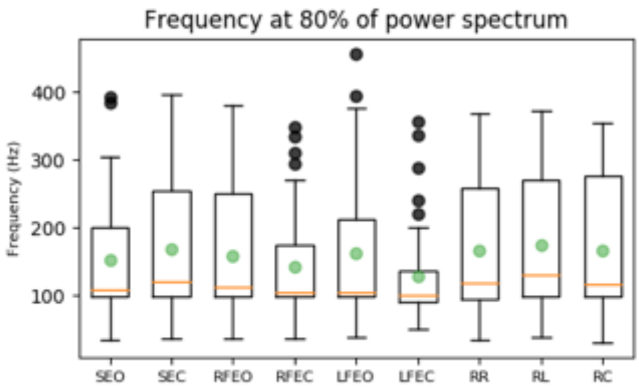
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1258	-							
RFEO	0.9639	0.1597	-						
RFEC	0.0162	0.0019	0.0002	-					
LFEO	0.8921	0.3579	0.3693	0.0089	-				
LFEC	0.0004	0.0002	0.0000	0.0722	0.0000	-			
RR	0.7256	0.4681	0.6189	0.0043	0.7614	0.0074	-		
RL	0.0178	0.3044	0.0503	0.0000	0.0808	0.0000	0.0960	-	
RC	0.7386	0.4895	0.5452	0.0018	0.8514	0.0004	0.5859	0.0118	-

Figure E.2 – Boxplot graphic and p-values between tasks, for mean frequency of RaR.



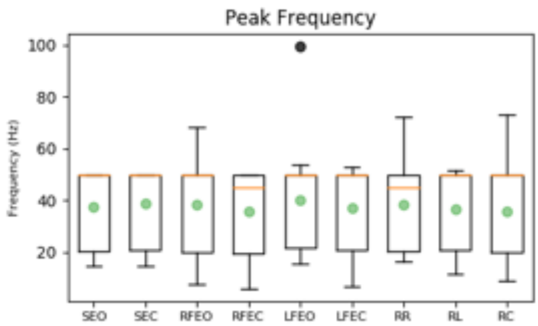
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0820	-							
RFEO	0.1346	0.8060	-						
RFEC	0.1619	0.1226	0.0023	-					
LFEO	0.5392	0.8350	0.6880	0.0325	-				
LFEC	0.6747	0.7399	0.1052	0.5248	0.0719	-			
RR	0.5775	0.3204	0.4083	0.0637	0.5124	0.2809	-		
RL	0.0222	0.1747	0.0026	0.0001	0.0468	0.0019	0.0481	-	
RC	0.9804	1.000	0.9363	0.0246	0.9091	0.0250	0.8651	0.0059	-

Figure E.3 – Boxplot graphic and p-values between tasks, for median frequency of RaR.



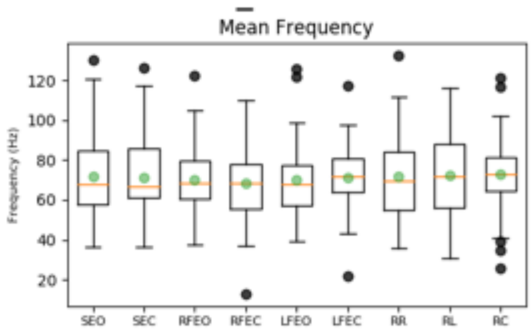
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0970	-							
RFEO	0.4222	0.4821	-						
RFEC	0.5219	0.2612	0.1635	-					
LFEO	0.1358	0.9959	0.8486	0.0274	-				
LFEC	0.0118	0.0019	0.0003	0.0085	0.0000	-			
RR	0.2509	0.8246	0.4781	0.0817	0.7957	0.0027	-		
RL	0.0088	0.1544	0.0326	0.0006	0.4402	0.0001	0.1895	-	
RC	0.0587	0.8562	0.0834	0.0067	0.7010	0.0006	0.7975	0.0540	-

Figure E.4 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of RaR.



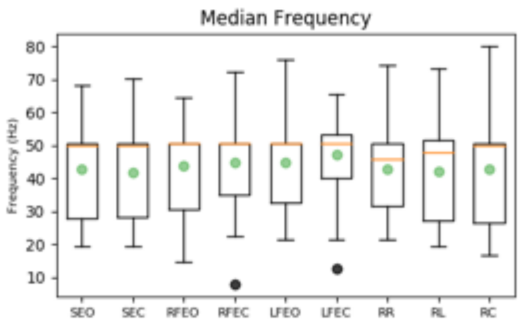
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1963	-							
RFEO	0.4497	0.2476	-						
RFEC	0.3252	0.0216	0.0208	-					
LFEO	0.0331	0.5298	0.1953	0.0037	-				
LFEC	0.7258	0.9594	0.6922	0.0508	0.2597	-			
RR	0.8823	0.6376	0.9720	0.0668	0.1472	0.9142	-		
RL	0.6811	0.8614	0.7884	0.0916	0.1596	0.6948	0.7459	-	
RC	0.8983	0.3785	0.4680	0.4407	0.0536	0.3219	0.2401	0.1002	-

Figure E.5 – Boxplot graphic and p-values between tasks, for peak frequency of RaL.



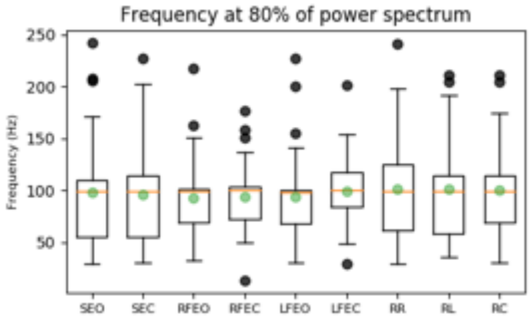
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.4602	-							
RFEO	0.6403	0.5004	-						
RFEC	0.5509	0.7127	0.8413	-					
LFEO	0.6099	0.3294	0.9571	0.6403	-				
LFEC	0.5086	0.4498	0.2063	0.0498	0.0935	-			
RR	0.6189	0.8211	0.4194	0.0764	0.4628	0.9126	-		
RL	0.2389	0.3557	0.2583	0.0171	0.5086	0.6159	0.8785	-	
RC	0.0178	0.0129	0.0441	0.0018	0.1597	0.1840	0.5338	0.7978	-

Figure E.6 – Boxplot graphic and p-values between tasks, for mean frequency of RaL.



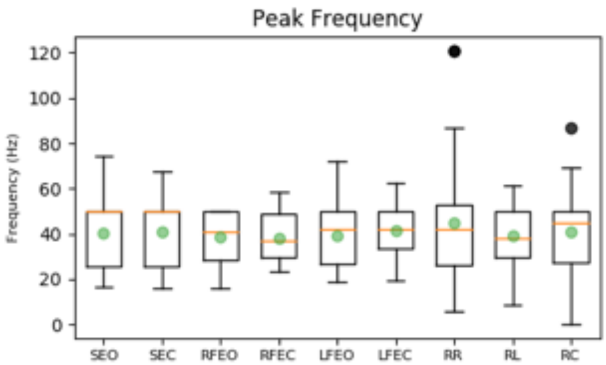
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1719	-							
RFEO	0.0398	0.0082	-						
RFEC	0.0015	0.0003	0.2346	-					
LFEO	0.0028	0.0003	0.1561	0.8829	-				
LFEC	0.0000	0.0000	0.0000	0.0084	0.0333	-			
RR	0.6835	0.8279	0.1500	0.0298	0.0164	0.0001	-		
RL	0.7141	0.1874	0.3883	0.0645	0.0565	0.0033	0.7523	-	
RC	0.6219	0.1117	0.8801	0.2636	0.1109	0.0044	0.6119	0.3808	-

Figure E.7 – Boxplot graphic and p-values between tasks, for median frequency of RaL.



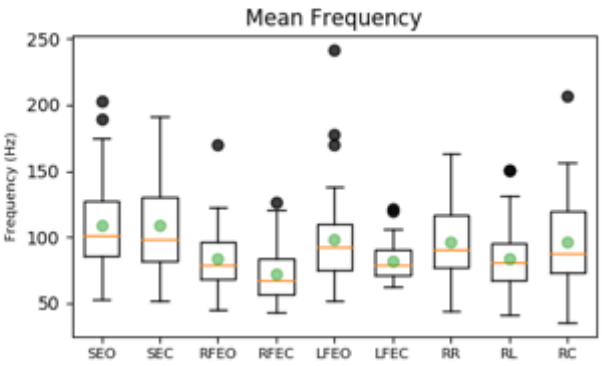
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1253	-							
RFEO	0.7743	0.8785	-						
RFEC	0.6664	0.6009	0.2647	-					
LFEO	0.2834	0.2105	0.2788	0.7027	-				
LFEC	0.1934	0.1434	0.0201	0.1542	0.0270	-			
RR	0.3251	0.2698	0.0894	0.0774	0.2182	0.9226	-		
RL	0.0540	0.0328	0.0689	0.0674	0.4340	0.7363	0.6697	-	
RC	0.0241	0.0209	0.0194	0.0240	0.2050	0.6656	0.7497	0.8445	-

Figure E.8– Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of RaL.



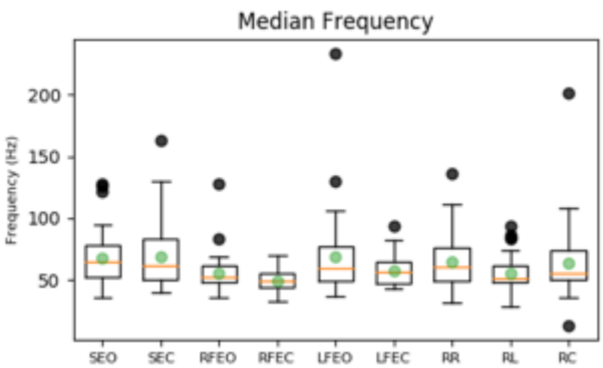
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.8452	-							
RFEO	0.0855	0.0725	-						
RFEC	0.0699	0.0195	0.6024	-					
LFEO	0.3940	0.2162	0.6448	0.3420	-				
LFEC	0.6733	0.7908	0.0353	0.0015	0.1834	-			
RR	0.1185	0.2253	0.0632	0.0241	0.0606	0.3911	-		
RL	0.3560	0.2938	0.7832	0.3295	0.9836	0.2311	0.1095	-	
RC	0.8205	0.6394	0.1950	0.0756	0.6569	0.7908	0.1295	0.4655	-

Figure E.9 – Boxplot graphic and p-values between tasks, for peak frequency of OL.



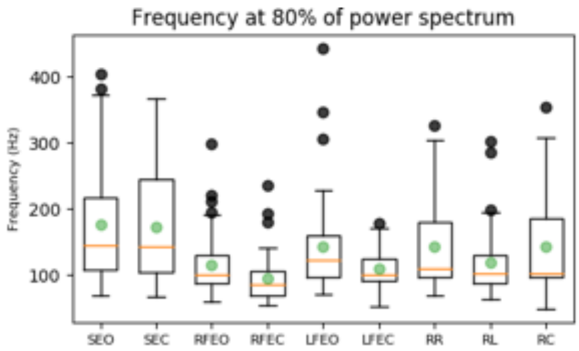
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.2063	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0002	-					
LFEO	0.0089	0.0103	0.0000	0.0000	-				
LFEC	0.0000	0.0000	0.7516	0.0000	0.0000	-			
RR	0.0068	0.0715	0.0001	0.0000	0.9502	0.0000	-		
RL	0.0000	0.0000	0.7845	0.0002	0.0003	0.8346	0.0000	-	
RC	0.0204	0.0757	0.0002	0.0000	0.5889	0.0005	0.9228	0.0001	-

Figure E.10 – Boxplot graphic and p-values between tasks, for mean frequency of OL.



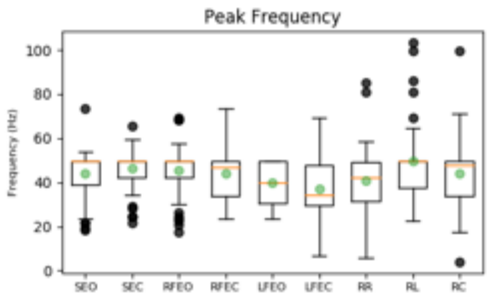
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.6555	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.8444	0.5843	0.0000	0.0000	-				
LFEC	0.0038	0.0022	0.0019	0.0000	0.0045	-			
RR	0.2119	0.3348	0.0001	0.0000	0.4330	0.0194	-		
RL	0.0000	0.0000	0.8910	0.0006	0.0000	0.0653	0.0000	-	
RC	0.3842	0.2035	0.0131	0.0000	0.1122	0.4599	0.2121	0.0009	-

Figure E.11 – Boxplot graphic and p-values between tasks, for median frequency of OL.



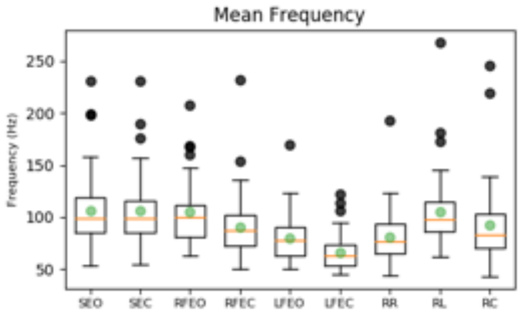
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1962	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0012	-					
LFEO	0.0048	0.0086	0.0001	0.0000	-				
LFEC	0.0000	0.0000	0.7620	0.0002	0.0000	-			
RR	0.0026	0.0455	0.0005	0.0000	0.6322	0.0000	-		
RL	0.0000	0.0000	0.7046	0.0002	0.0014	0.8878	0.0007	-	
RC	0.0024	0.0305	0.0027	0.0000	0.7617	0.0018	0.8596	0.0011	-

Figure E.12 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of OL.



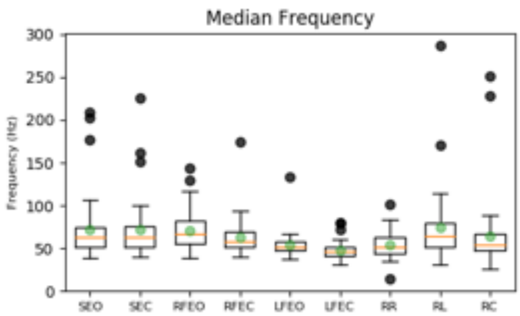
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0119	-							
RFEO	0.0880	0.7803	-						
RFEC	0.9647	0.0905	0.4614	-					
LFEO	0.0042	0.0000	0.0006	0.0228	-				
LFEC	0.0001	0.0000	0.0000	0.0001	0.0239	-			
RR	0.0689	0.0021	0.0037	0.1092	0.5013	0.0072	-		
RL	0.8958	0.1617	0.0315	0.0046	0.0000	0.0000	0.0001	-	
RC	0.0024	0.3021	0.4616	0.7446	0.0574	0.0002	0.0372	0.0111	-

Figure E.13 – Boxplot graphic and p-values between tasks, for peak frequency of OR.



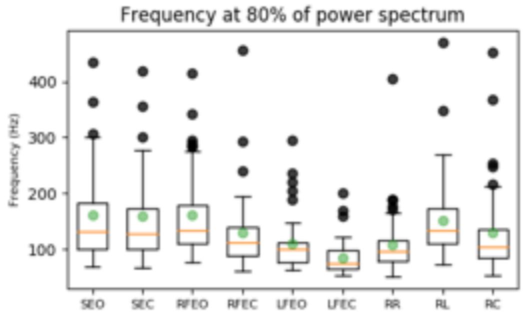
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.9399	-							
RFEO	0.4841	0.1087	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0000	0.0001	-				
LFEC	0.0000	0.0000	0.0000	0.0000	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0012	0.7353	0.0000	-		
RL	0.4576	0.6281	0.6342	0.0000	0.0000	0.0000	0.0000	-	
RC	0.0001	0.0001	0.0006	0.9708	0.0031	0.0000	0.0001	0.0001	-

Figure E.14 – Boxplot graphic and p-values between tasks, for mean frequency of OR.



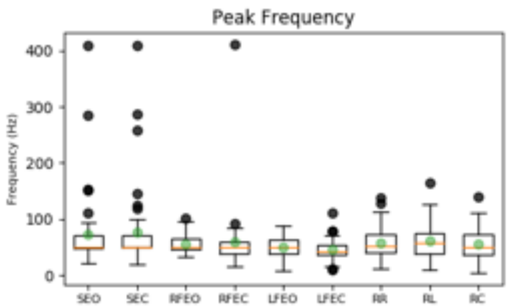
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.8440	-							
RFEO	0.2451	0.2656	-						
RFEC	0.0505	0.0211	0.0002	-					
LFEO	0.0000	0.0000	0.0000	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.0000	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0000	0.5234	0.0001	-		
RL	0.2592	0.2791	0.8553	0.0018	0.0000	0.0000	0.0000	-	
RC	0.0024	0.0004	0.0001	0.0217	0.0199	0.0000	0.0019	0.0001	-

Figure E.15 – Boxplot graphic and p-values between tasks, for median frequency of OR.



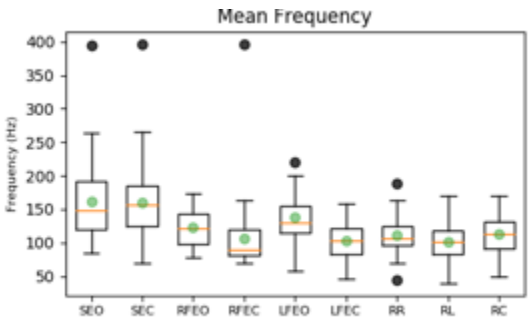
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.9062	-							
RFEO	0.8284	0.6841	-						
RFEC	0.0000	0.0001	0.0000	-					
LFEO	0.0000	0.0000	0.0000	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.0000	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0002	0.7515	0.0000	-		
RL	0.2196	0.4065	0.0703	0.0000	0.0000	0.0000	0.0000	-	
RC	0.0004	0.0008	0.0001	0.4787	0.0325	0.0000	0.0009	0.0003	-

Figure E.16 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of OR.



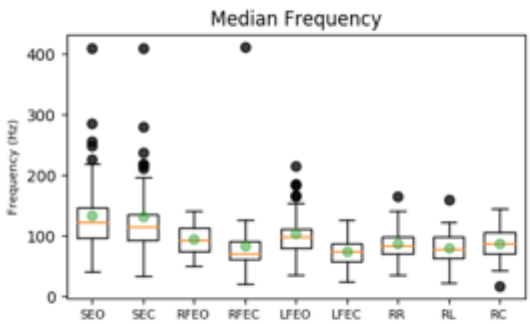
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.8409	-							
RFEO	0.5330	0.3177	-						
RFEC	0.0063	0.0041	0.0065	-					
LFEO	0.0021	0.0007	0.0285	0.7370	-				
LFEC	0.0000	0.0000	0.0000	0.0094	0.0158	-			
RR	0.1143	0.1446	0.9236	0.0708	0.1661	0.0001	-		
RL	0.8865	0.9858	0.2430	0.0013	0.0285	0.0001	0.1357	-	
RC	0.2158	0.0741	0.3570	0.5801	0.7958	0.0045	0.7939	0.1733	-

Figure E.17 – Boxplot graphic and p-values between tasks, for peak frequency of MR.



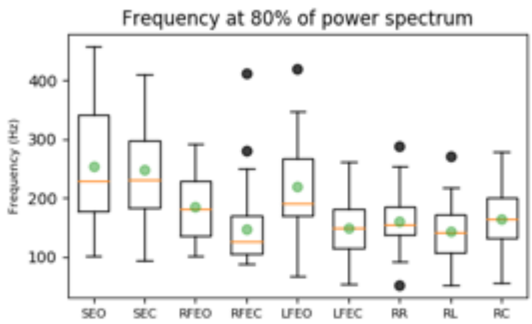
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1497	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0011	0.0054	0.0137	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.3044	0.0000	-			
RR	0.0000	0.0000	0.0016	0.0006	0.0000	0.0123	-		
RL	0.0000	0.0000	0.0000	0.0918	0.0000	0.6434	0.0015	-	
RC	0.0000	0.0000	0.0043	0.0001	0.0000	0.01170	0.6068	0.0002	-

Figure E.18 – Boxplot graphic and p-values between tasks, for mean frequency of MR.



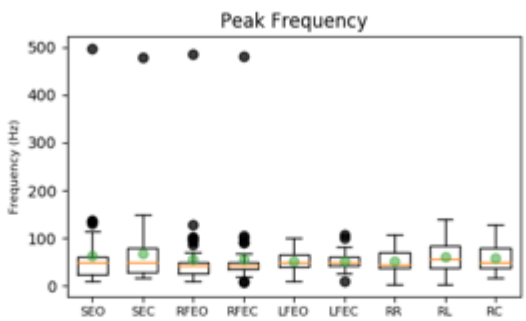
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1287	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0003	0.0028	0.3578	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.8819	0.0000	-			
RR	0.0000	0.0000	0.0065	0.0004	0.0027	0.0001	-		
RL	0.0000	0.0000	0.0000	0.0751	0.0000	0.2711	0.0028	-	
RC	0.0000	0.0000	0.0583	0.0001	0.0091	0.0002	0.2982	0.0003	-

Figure E.19 – Boxplot graphic and p-values between tasks, for median frequency of MR.



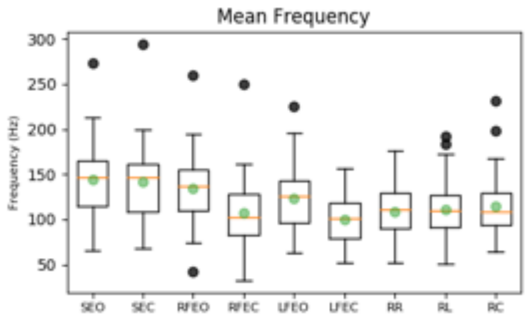
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0257	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0173	0.0267	0.0068	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.1695	0.0000	-			
RR	0.0000	0.0000	0.0042	0.0015	0.0000	0.0445	-		
RL	0.0000	0.0000	0.0000	0.1610	0.0000	0.3715	0.0008	-	
RC	0.0000	0.0000	0.0062	0.0002	0.0000	0.0256	0.4618	0.0002	-

Figure E.20 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of MR.



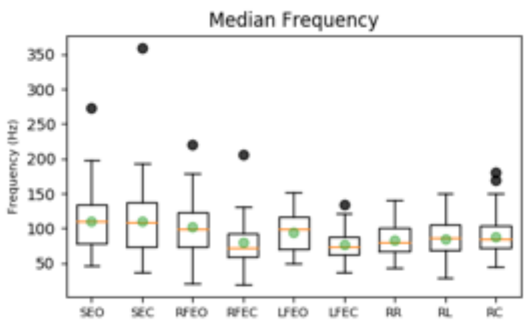
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0570	-							
RFEO	0.0495	0.0001	-						
RFEC	0.5656	0.0108	0.5840	-					
LFEO	0.7646	0.1106	0.0799	0.3554	-				
LFEC	0.5515	0.4504	0.0765	0.1572	0.2498	-			
RR	0.8935	0.3028	0.1031	0.3242	0.9006	0.6491	-		
RL	0.0668	0.5360	0.0076	0.0017	0.0360	0.0344	0.0352	-	
RC	0.1370	0.6486	0.0073	0.0200	0.1295	0.3137	0.0466	0.7552	-

Figure E.21 – Boxplot graphic and p-values between tasks, for peak frequency of ML.



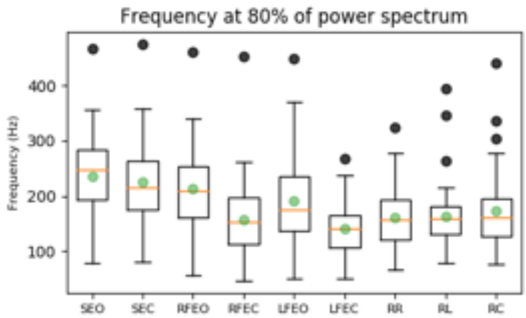
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.7516	-							
RFEO	0.0065	0.0415	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0273	0.0022	-				
LFEC	0.0000	0.0000	0.0000	0.0708	0.0000	-			
RR	0.0000	0.0000	0.0000	0.4922	0.0011	0.0079	-		
RL	0.0000	0.0000	0.0000	0.4023	0.0010	0.0005	0.1702	-	
RC	0.0000	0.0000	0.0000	0.0800	0.1798	0.0000	0.0270	0.0918	-

Figure E.22 – Boxplot graphic and p-values between tasks, for mean frequency of ML.



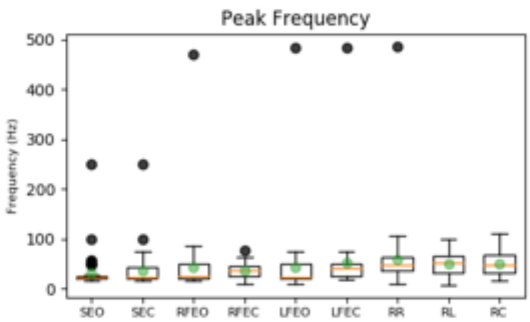
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.7253	-							
RFEO	0.1185	0.0551	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0001	0.0029	0.1899	0.0005	-				
LFEC	0.0000	0.0000	0.0000	0.4836	0.0000	-			
RR	0.0000	0.0000	0.0001	0.1238	0.0025	0.0237	-		
RL	0.0000	0.0000	0.0004	0.0773	0.0026	0.0085	0.1760	-	
RC	0.0000	0.0000	0.0237	0.0218	0.2031	0.0021	0.1177	0.2194	-

Figure E.23 – Boxplot graphic and p-values between tasks, for median frequency of ML.



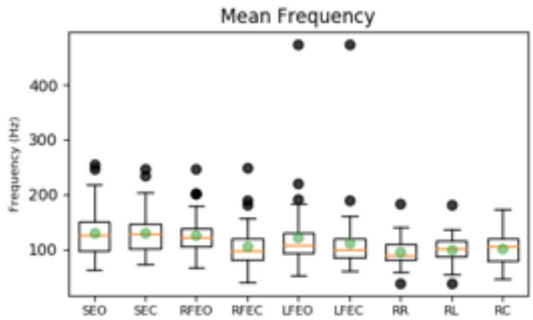
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.3264	-							
RFEO	0.0069	0.0601	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0143	0.0081	-				
LFEC	0.0000	0.0000	0.0000	0.0153	0.0000	-			
RR	0.0000	0.0000	0.0000	0.6008	0.0088	0.0024	-		
RL	0.0000	0.0000	0.0000	0.8689	0.0022	0.0003	0.5323	-	
RC	0.0000	0.0000	0.0001	0.0337	0.2529	0.0000	0.0766	0.0467	-

Figure E.24 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of ML.



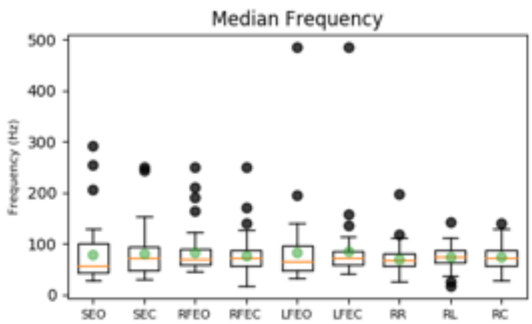
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.7122	-							
RFEO	0.0025	0.0262	-						
RFEC	0.0001	0.0034	0.1214	-					
LFEO	0.1427	0.0996	0.3925	0.0580	-				
LFEC	0.0000	0.0000	0.0000	0.0035	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0003	0.0000	0.0236	-		
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0012	0.7013	-	
RC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0173	0.6651	0.8261	-

Figure E.25 – Boxplot graphic and p-values between tasks, for peak frequency of IL.



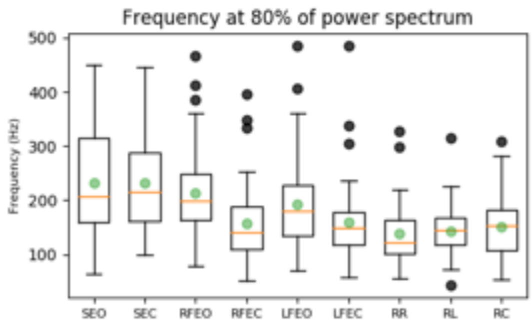
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1379	-							
RFEO	0.1743	0.0702	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0001	0.0000	0.0000	0.0722	-				
LFEC	0.0000	0.0000	0.0000	0.3903	0.0009	-			
RR	0.0000	0.0000	0.0000	0.0902	0.0001	0.0195	-		
RL	0.0000	0.0000	0.0000	0.2885	0.0059	0.5059	0.0478	-	
RC	0.0000	0.0000	0.0000	0.5800	0.0295	0.2885	0.0381	0.5538	-

Figure E.26 – Boxplot graphic and p-values between tasks, for mean frequency of IL.



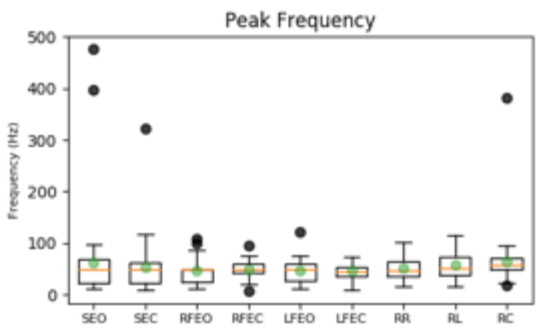
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0089	-							
RFEO	0.0843	0.3208	-						
RFEC	0.6421	0.5323	0.0337	-					
LFEO	0.6881	0.2031	0.0007	0.1093	-				
LFEC	0.3605	0.7212	0.3187	0.9885	0.1071	-			
RR	0.9262	0.3208	0.1103	0.2301	0.9023	0.0258	-		
RL	0.5493	0.9715	0.2005	0.7855	0.2730	0.2892	0.0607	-	
RC	0.3785	0.9948	0.4013	0.8200	0.6465	0.2284	0.1960	0.9296	-

Figure E.27 – Boxplot graphic and p-values between tasks, for median frequency of IL.



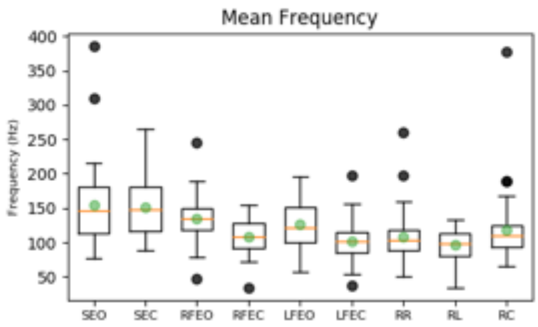
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.4865	-							
RFEO	0.0016	0.0002	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0000	0.0001	-				
LFEC	0.0000	0.0000	0.0000	0.4601	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0111	0.0000	0.0197	-		
RL	0.0000	0.0000	0.0000	0.0695	0.0000	0.3535	0.2629	-	
RC	0.0000	0.0000	0.0000	0.9057	0.0014	0.5338	0.0085	0.0211	-

Figure E.28 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of IL.



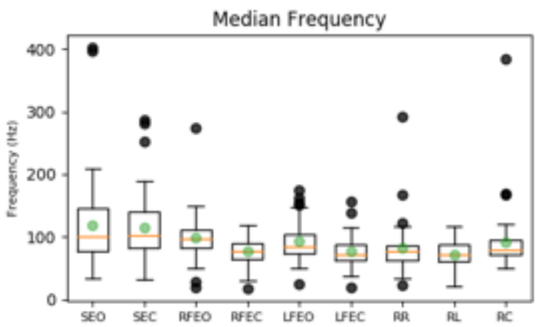
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.5080	-							
RFEO	0.5374	0.1405	-						
RFEC	0.1590	0.3956	0.0715	-					
LFEO	0.2566	0.3935	0.7444	0.0879	-				
LFEC	0.7600	0.8753	0.8328	0.0238	0.9107	-			
RR	0.5207	0.3091	0.2389	0.7212	0.2126	0.1184	-		
RL	0.0051	0.0048	0.0004	0.0051	0.0012	0.0001	0.0128	-	
RC	0.0016	0.0046	0.0002	0.0014	0.0000	0.0000	0.0026	0.8082	-

Figure E.29 – Boxplot graphic and p-values between tasks, for peak frequency of IR.



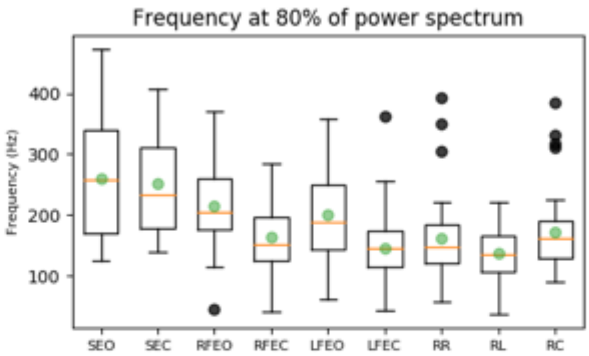
	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.6714	-							
RFEO	0.0003	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0001	0.0000	0.0441	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.0034	0.0000	-			
RR	0.0000	0.0000	0.0000	0.4023	0.0000	0.6159	-		
RL	0.0000	0.0000	0.0000	0.0001	0.0000	0.1756	0.0013	-	
RC	0.0000	0.0000	0.0000	0.4472	0.0003	0.0869	0.0027	0.0000	-

Figure E.30 – Boxplot graphic and p-values between tasks, for mean frequency of IR.



	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.6348	-							
RFEO	0.0197	0.0001	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0142	0.0004	0.4143	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.0826	0.0000	-			
RR	0.0000	0.0000	0.0000	0.3293	0.0000	0.8441	-		
RL	0.0000	0.0000	0.0000	0.0475	0.0000	0.2983	0.0826	-	
RC	0.0000	0.0000	0.0002	0.2389	0.0031	0.0674	0.0069	0.0002	-

Figure E.31 – Boxplot graphic and p-values between tasks, for median frequency of IR.



	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.6683	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0682	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.0025	0.0000	-			
RR	0.0000	0.0000	0.0000	0.2845	0.0000	0.5003	-		
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.3808	0.0006	-	
RC	0.0000	0.0000	0.0000	0.7321	0.0005	0.0668	0.1268	0.0000	-

Figure E.31 – Boxplot graphic and p-values between tasks, for 80% of power spectrum frequency of IR.

F

Appendix F

In this appendix it will be presented the results from the Wilcoxon Test for the COP parameters studied.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.9297	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0854	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.7095	0.0000	-			
RR	0.0000	0.0000	0.0831	0.0000	0.8379	0.0000	-		
RL	0.0000	0.0000	0.0101	0.0000	0.2620	0.0000	0.8145	-	
RC	0.0000	0.0000	0.2826	0.0000	0.0513	0.0000	0.0006	0.0000	-

Figure F.1- Representation of p-values from the Wilcoxon test, between tasks for COP amplitude in the x direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0180	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.1957	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.7647	0.0000	-			
RR	0.0000	0.0000	0.0831	0.5654	0.0000	0.0188	-		
RL	0.0000	0.0000	0.0101	0.0545	0.0000	0.0003	0.0026	-	
RC	0.0000	0.0000	0.2826	0.0389	0.0000	0.0007	0.0005	0.0464	-

Figure F.2- Representation of p-values from the Wilcoxon test, between tasks for COP amplitude in the y direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.5859	-							
RFEO	0.0000	0.0000	-						
RFEC	[illegible]	[illegible]	[illegible]	-					
LFEO	0.0000	0.0000	0.0008	0.0000	-				
LFEC	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-			
RR	0.0000	0.0000	0.0000	0.1185	0.0000	0.0567	-		
RL	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-	
RC	0.0000	0.0000	0.0000	0.0000	0.0135	0.0000	0.0001	0.0000	-

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0682	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.1675	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.3424	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-		
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0540	-	
RC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0002	0.0242	-

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0682	-							
RFEO	0.4576	0.5225	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0043	0.9331	0.3951	0.0000	-				
LFEC	0.0006	0.0026	0.0006	0.0000	0.0166	-			
RR	0.0000	0.0000	0.0000	0.0007	0.0000	0.0000	-		
RL	0.0000	0.0001	0.0001	0.0000	0.0001	0.0019	0.0000	-	

Figure F.4 - Representation of p-values from the Wilcoxon Test between tasks for standard deviation of COP signals in the y direction.

Figure F.5 - Representation of p-values from the Wilcoxon Test between tasks for COP's mean velocity in the x direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.1826	-							
RFEO	0.5225	0.1226	-						
RFEC	0.8011	0.6038	0.6129	-					
LFEO	0.2731	0.0644	0.8178	0.6496	-				
LFEC	0.8955	0.5538	0.6621	0.8853	0.4949	-			
RR	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	-		
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0715	-	
RC	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0085	0.9536	-

Figure F.6 - Representation of p-values from the Wilcoxon Test between tasks for COP's mean velocity in the y direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0270	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.0059	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.6558	0.0000	-			
RR	0.0000	0.0000	0.0000	0.0000	0.0573	0.0000	-		
RL	0.0000	0.0000	0.0001	0.0000	0.0315	0.0000	0.8312	-	
RC	0.0000	0.0000	0.0024	0.0000	0.3105	0.0000	0.0450	0.0625	-

Figure F.7 - Representation of p-values from the Wilcoxon Test between tasks for COP's total area.

G

Appendix G

In this appendix it will be presented the results from the Wilcoxon Test for the COP frequencies studied.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.5423	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.1547	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.7516	0.0000	-			
RR	0.0000	0.0000	0.0318	0.0000	0.1067	0.0003	-		
RL	0.0000	0.0000	0.0000	0.0000	0.0000	0.0026	0.0123	-	
RC	0.0000	0.0000	0.5625	0.0000	0.4472	0.0000	0.0016	0.0000	-

Figure G.1 - Representation of p-values from the Wilcoxon Test, between tasks for mean frequency of COP signals in the x direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0212	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.9610	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.2016	0.0000	-			
RR	0.0000	0.0000	0.0048	0.2609	0.0079	0.2989	-		
RL	0.0000	0.0000	0.0000	0.1107	0.0000	0.4486	0.8786	-	
RC	0.0000	0.0000	0.0026	0.2016	0.0031	0.6077	0.5740	0.8022	-

Figure G.2 - Representation of p-values from the Wilcoxon Test, between tasks for mean frequency of COP signals in the y direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0092	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0002	0.0927	-					
LFEO	0.0000	0.0000	0.5802	0.0586	-				
LFEC	0.0000	0.0000	0.7787	0.1585	0.9644	-			
RR	0.0000	0.0000	0.0341	0.6280	0.0258	0.1083	-		
RL	0.0000	0.0002	0.0005	0.0777	0.0001	0.0039	0.1473	-	
RC	0.0000	0.0000	0.6840	0.0861	0.8480	0.5219	0.0341	0.0002	-

Figure G.3 - Representation of p-values from the Wilcoxon Test, between tasks for 80% of power spectrum frequency of COP signals in the x direction.

	SEO	SEC	RFEO	RFEC	LFEO	LFEC	RR	RL	RC
SEO	-								
SEC	0.0040	-							
RFEO	0.0000	0.0000	-						
RFEC	0.0000	0.0000	0.0000	-					
LFEO	0.0000	0.0000	0.1822	0.0000	-				
LFEC	0.0000	0.0000	0.0000	0.6723	0.0000	-			
RR	0.0000	0.0000	0.4194	0.0000	0.0867	0.0000	-		
RL	0.0000	0.0002	0.9751	0.0000	0.2466	0.0000	0.2418	-	
RC	0.0000	0.0000	0.2641	0.0000	0.8442	0.0001	0.1613	0.1653	-

Figure G.4 - Representation of p-values from the Wilcoxon Test, between tasks for 80% of power spectrum frequency of COP signals in the y direction.

H

Appendix H

In this appendix it will be presented the results from the paired samples t-Test for the EMG frequencies studied.

	RAL	RAR	OL	OR	IL	IR	ML	MR
RFEO	0.8797	0.3051	0.1812	0.3139	0.2987	0.9121	0.3622	0.5549
RFEC	0.4565	0.2702	0.3102	0.9722	0.1013	0.3868	0.4878	0.4990
LFEO	0.6569	0.4271	0.2298	0.5338	0.3061	0.5453	0.8035	0.1411
LFEC	0.6579	0.5253	0.3064	0.3016	0.4846	0.8925	0.2752	0.4267
SEO	0.5337	0.2457	0.1589	0.8282	0.8924	0.8082	0.7795	0.1733
SEC	0.6093	0.1360	0.6262	0.7986	0.6187	0.7543	0.6727	0.2535
RL	0.9331	0.6028	0.2311	0.6031	0.8584	0.5473	0.5450	0.7264
RC	0.5638	0.9101	0.1375	0.3028	0.4856	0.4226	0.7130	0.0139
RR	0.9847	0.7336	0.2413	0.9493	0.8060	0.4414	0.4994	0.1265

Figure H.1 – Representation of p-values from the paired samples t-Test, for peak frequency.

	RAL	RAR	OL	OR	IL	IR	ML	MR
RFEO	0.1895	0.2098	0.1321	0.9150	0.3347	0.9792	0.1444	0.3238
RFEC	0.2049	0.7177	0.6743	0.1860	0.9082	0.3501	0.1285	0.7416
LFEO	0.3956	0.9930	0.4115	0.9573	0.8483	0.5965	0.6583	0.5809
LFEC	0.8625	0.8171	0.3835	0.5045	0.6526	0.8604	0.6516	0.0041
SEO	0.5755	0.4137	0.2260	0.5855	0.5658	0.3866	0.1133	0.4244
SEC	0.4574	0.8735	0.3835	0.3013	0.3631	0.7000	0.0774	0.4064
RL	0.5874	0.7105	0.1348	0.6500	0.0669	0.2427	0.8820	0.0727
RC	0.3374	0.8853	0.1383	0.0868	0.1297	0.0770	0.7632	0.0506
RR	0.9551	0.9132	0.1830	0.8245	0.1049	0.7117	0.6897	0.2235

Figure H.2 – Representation of p-values from the paired samples t-Test for the mean frequency.

	RAL	RAR	OL	OR	IL	IR	ML	MR
RFEO	0.2795	0.2357	0.2140	0.7258	0.3777	0.6270	0.3676	0.4065
RFEC	0.1228	0.4728	0.3333	0.3696	0.7649	0.6142	0.2588	0.7234
LFEO	0.8181	0.9422	0.5619	0.7526	0.8025	0.3015	0.4455	0.6312
LFEC	0.6824	0.5956	0.2328	0.2743	0.4285	0.5562	0.9658	0.0079
SEO	0.7645	0.9809	0.1654	0.5212	0.9162	0.2832	0.0801	0.5161
SEC	0.5682	0.7289	0.7396	0.7267	0.8254	0.5015	0.1450	0.5500
RL	0.5968	0.6029	0.1130	0.4667	0.2025	0.7336	0.8462	0.3215
RC	0.2390	0.4343	0.1263	0.0606	0.4532	0.3719	0.7124	0.0547
RR	0.6263	0.8852	0.3747	0.3060	0.1688	0.4308	0.7977	0.4249

Figure H.3 – Representation of p-values from the paired samples t-Test for median frequencies

Appendix I

In this appendix it will be presented the results regarding the mean and median values of EMG arrays analysis, between the two groups studied.

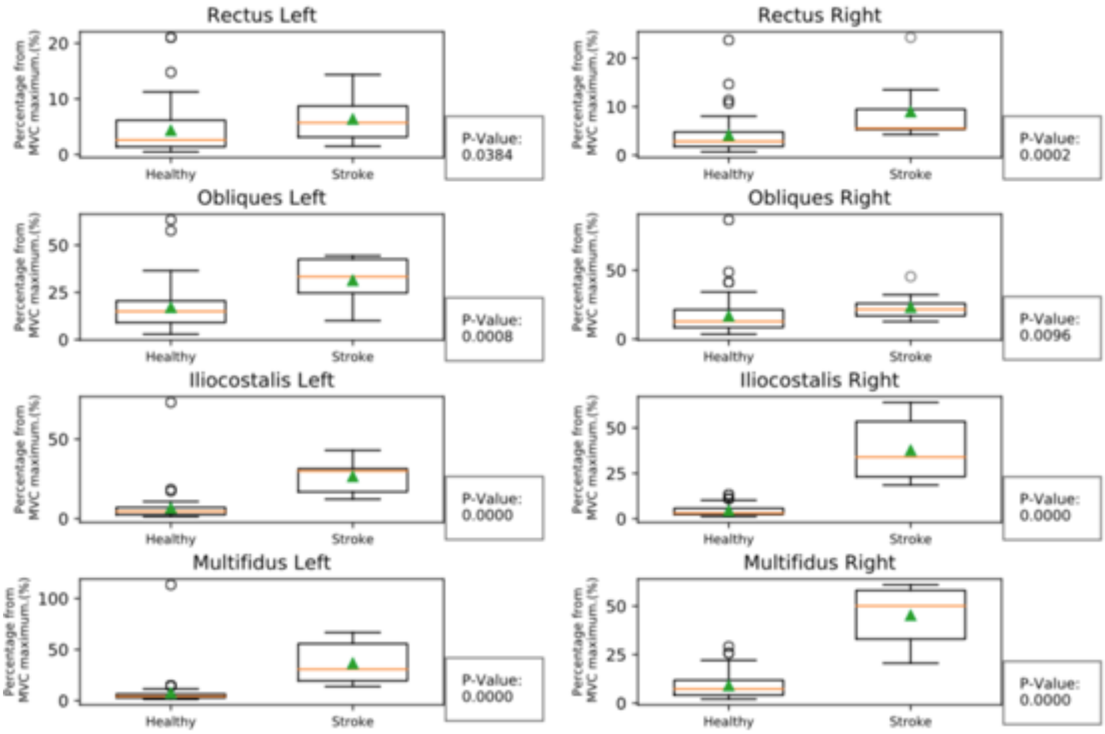


Figure I.1 – Boxplot graphic of mean values and p-values between both samples, for SEC task.

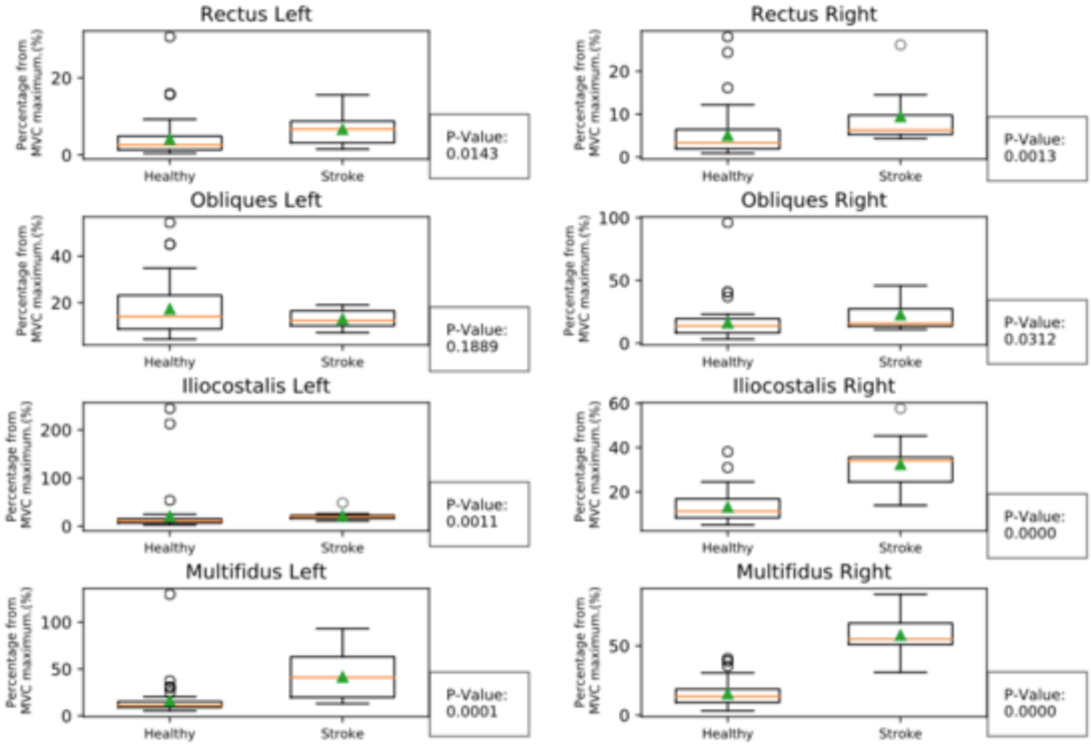


Figure I.2 – Boxplot graphic of mean values and p-values between both samples, for SEO task.

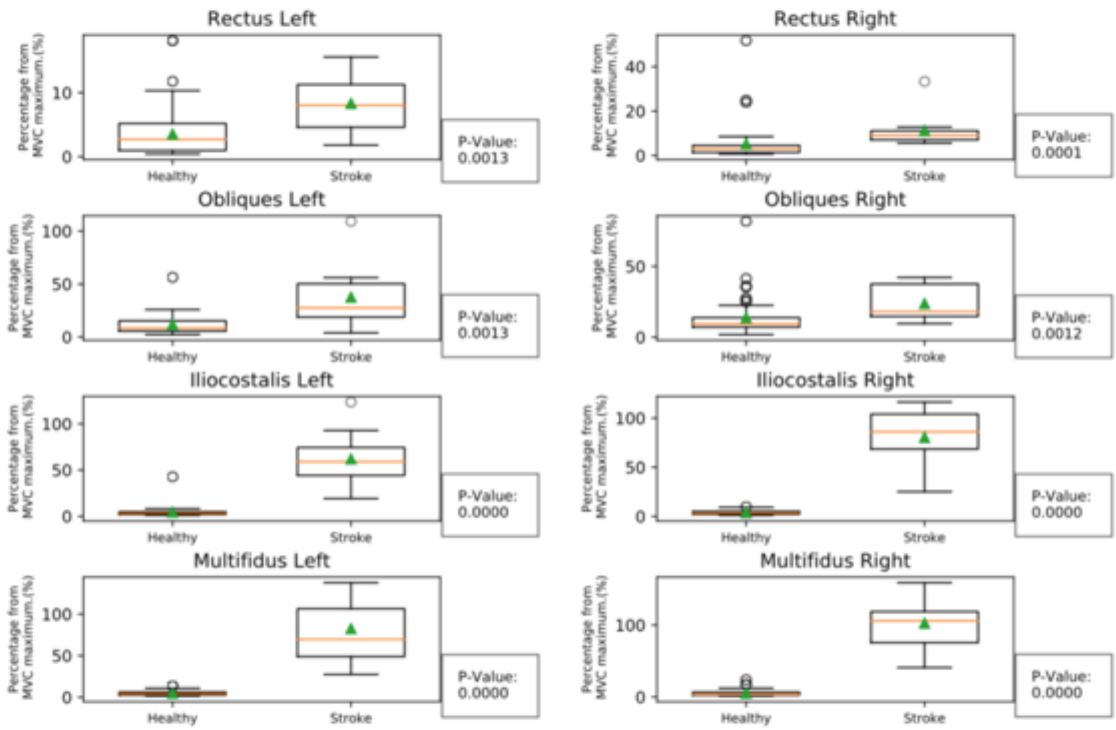


Figure I.3 – Boxplot graphic of mean values and p-values between both samples, for RR task.

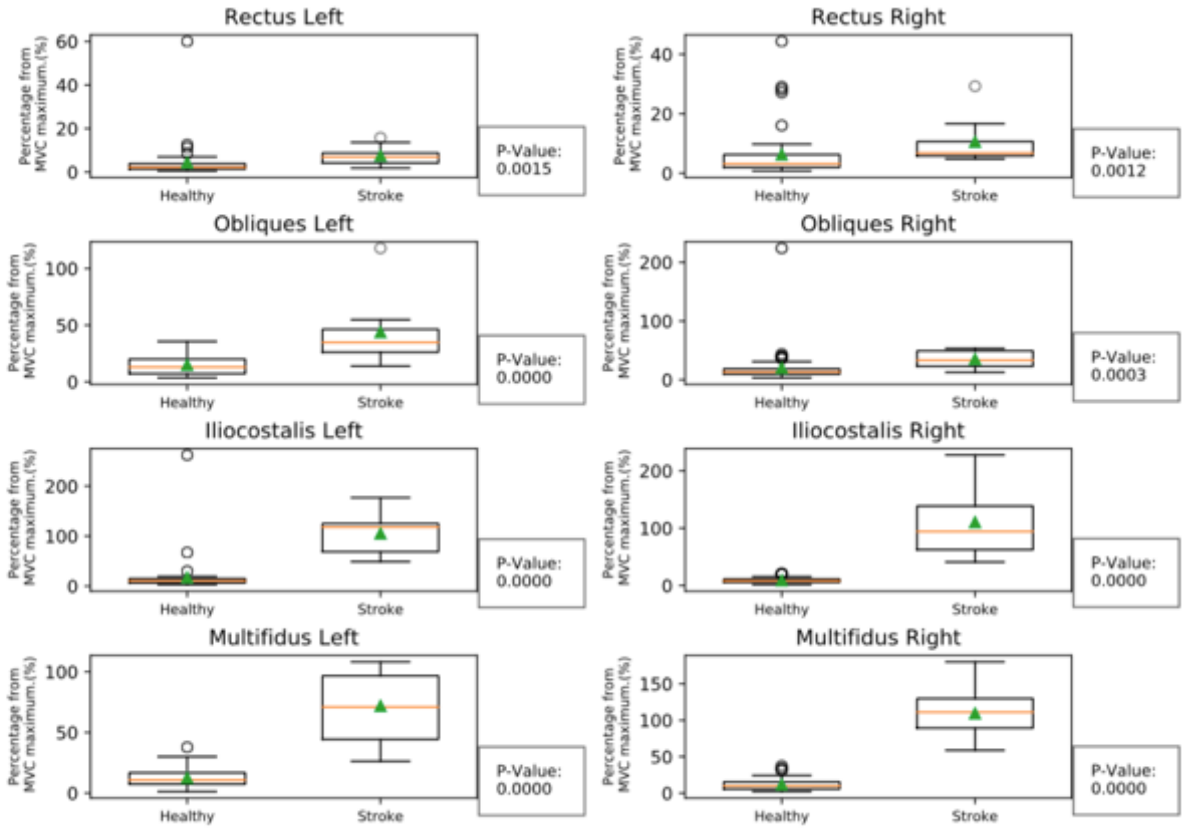


Figure I.4 – Boxplot graphic of mean values and p-values between both samples, for RC task.

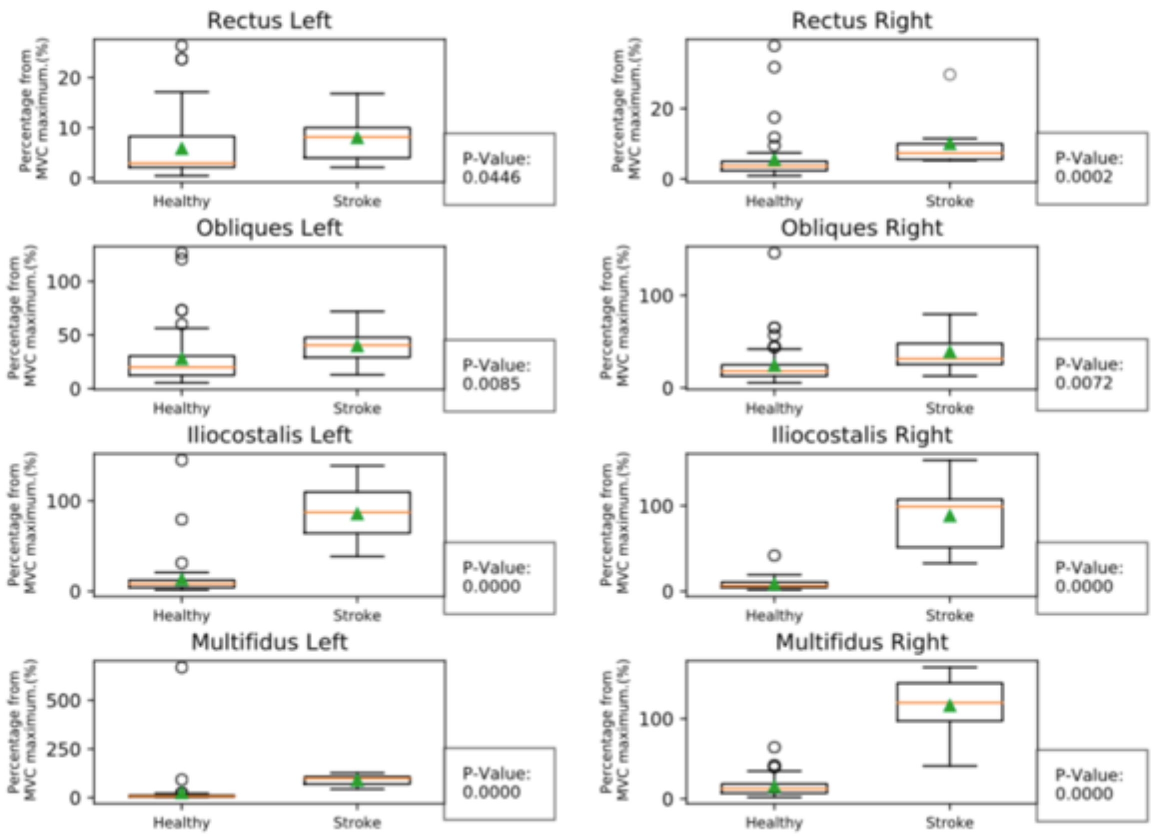


Figure I.5 – Boxplot graphic of mean values and p-values between both samples, for RL task.

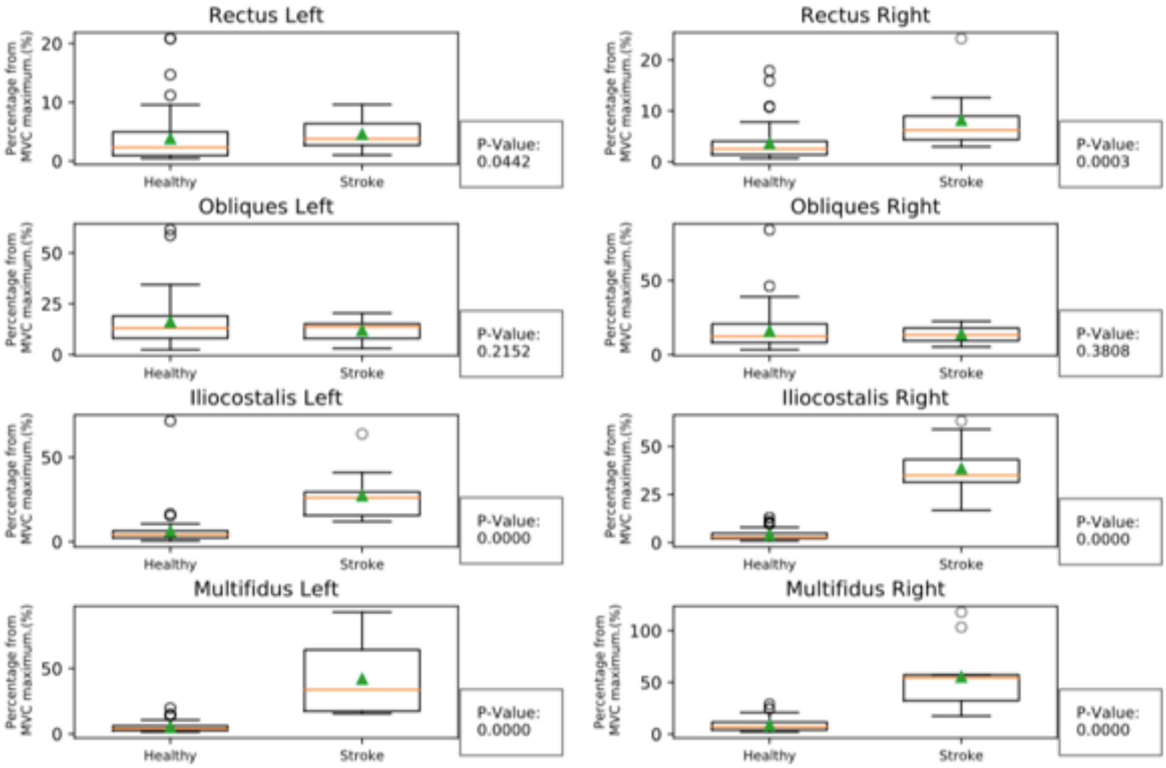


Figure I.6 – Boxplot graphic of median values and p-values between both samples, for SEC task.

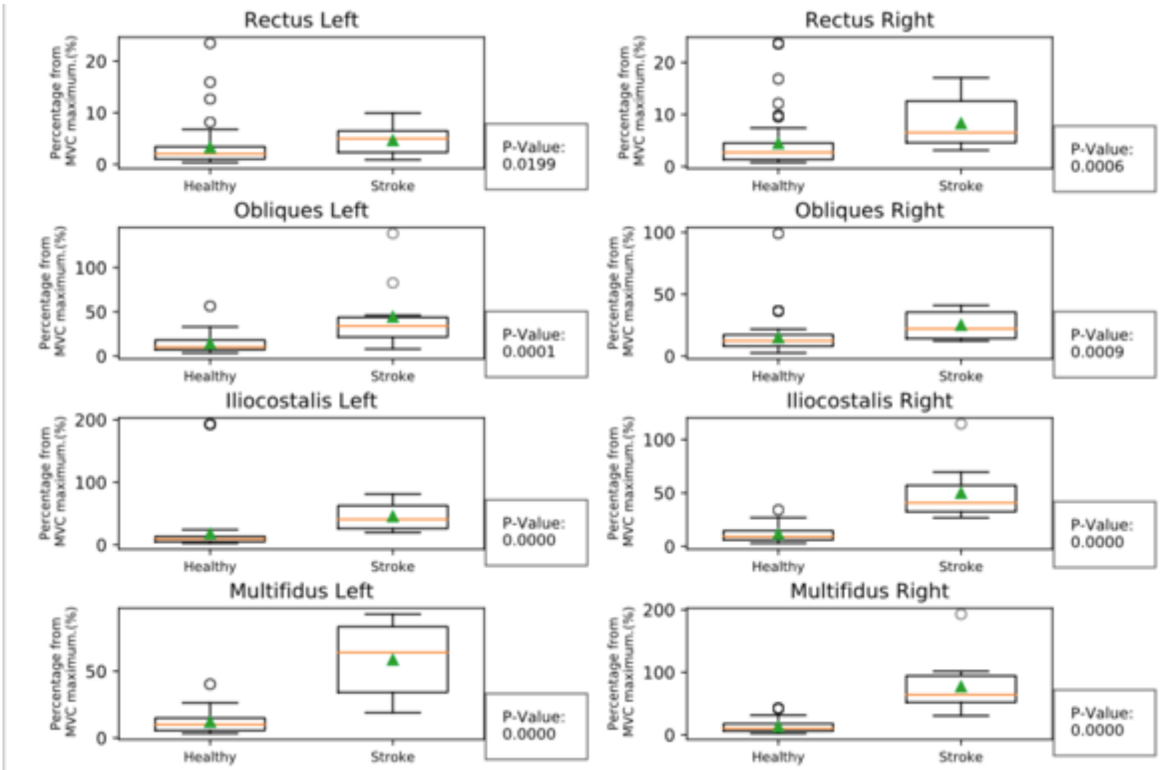


Figure I.7 – Boxplot graphic of median values and p-values between both samples, for SEO task.

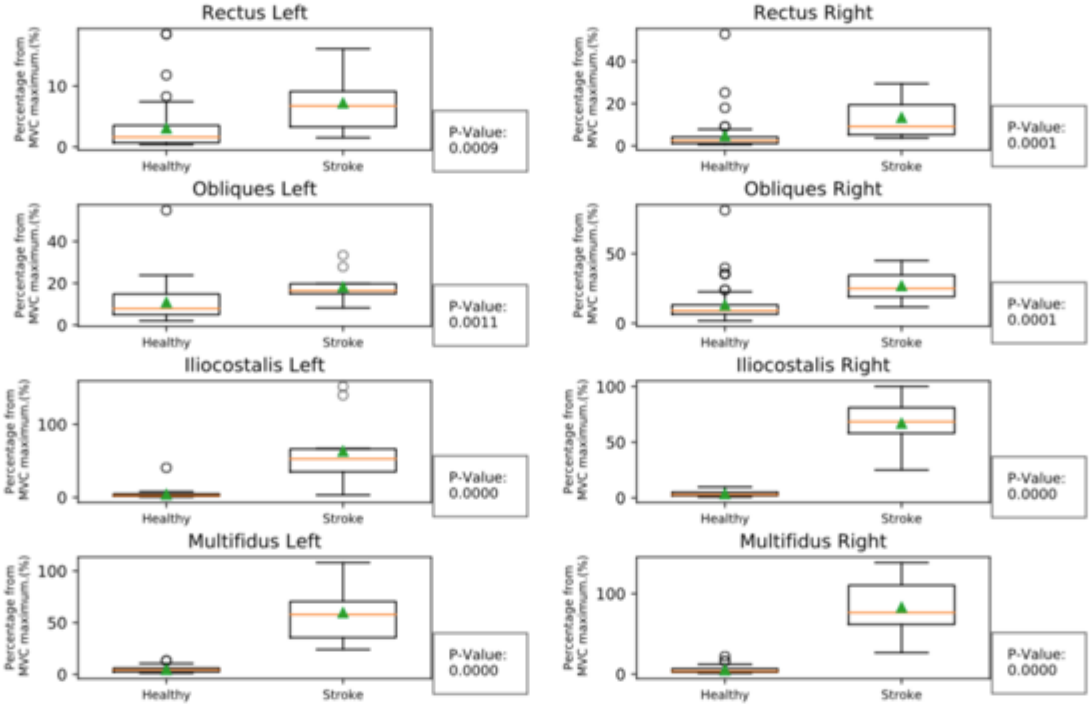


Figure I.8 – Boxplot graphic of median values and p-values between both samples, for RR task.

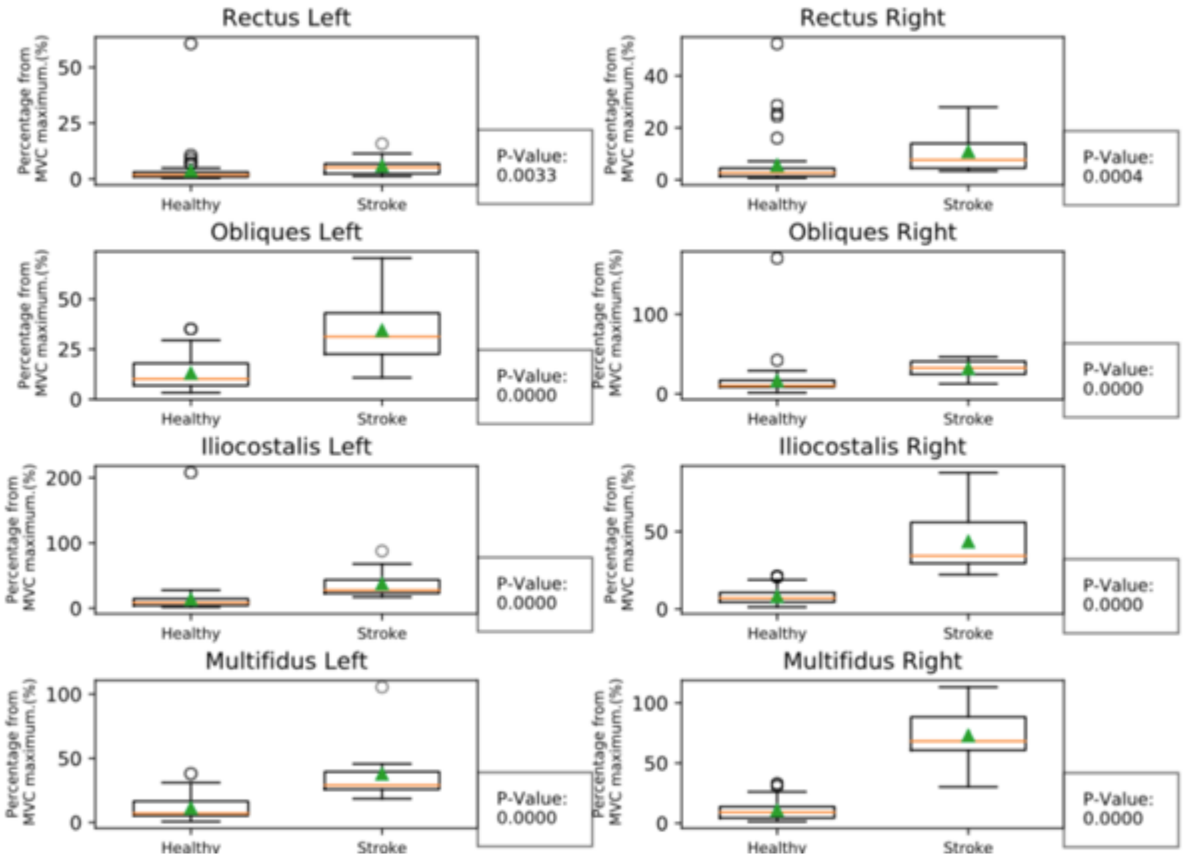


Figure I.9 – Boxplot graphic of median values and p-values between both samples, for RC task.

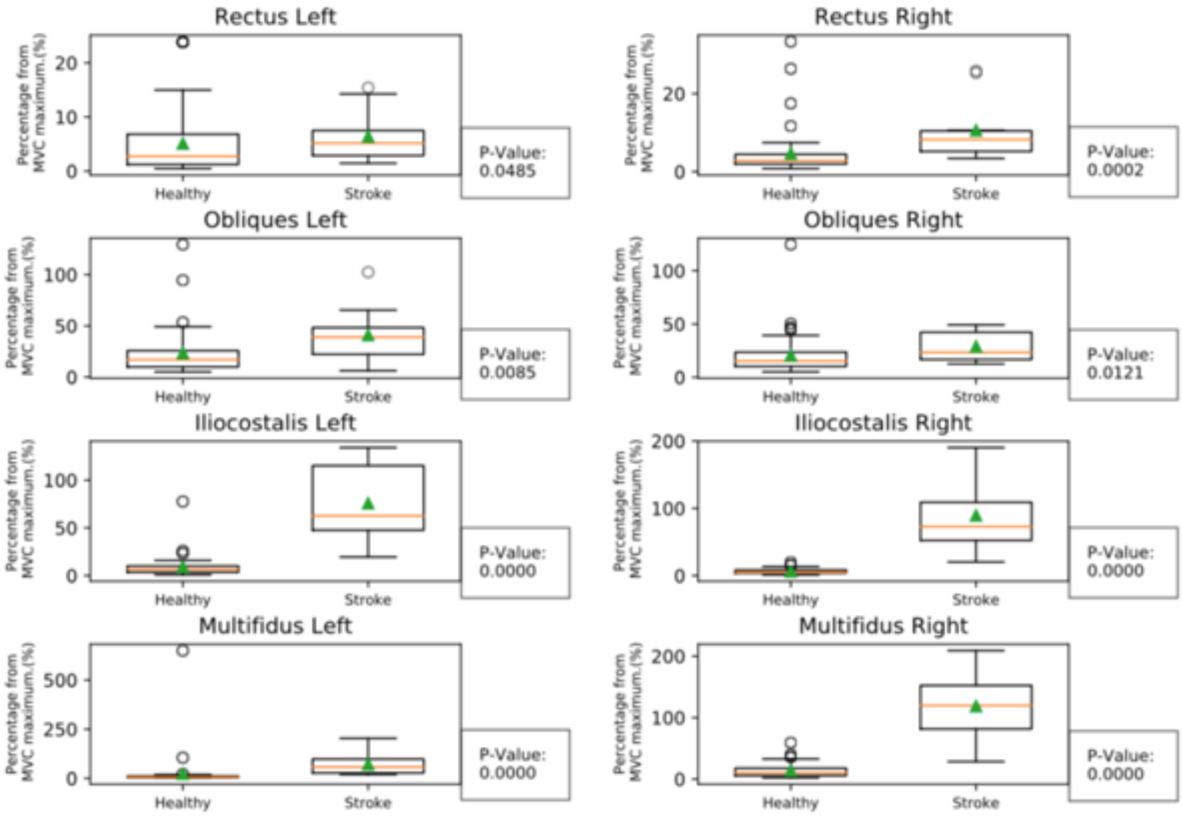


Figure I.10 – Boxplot graphic of median values and p-values between both samples, for RL task.

J

Appendix J

In this appendix it will be presented the results concerning the mean values of EMG arrays analysis during rest, of the two groups studied.

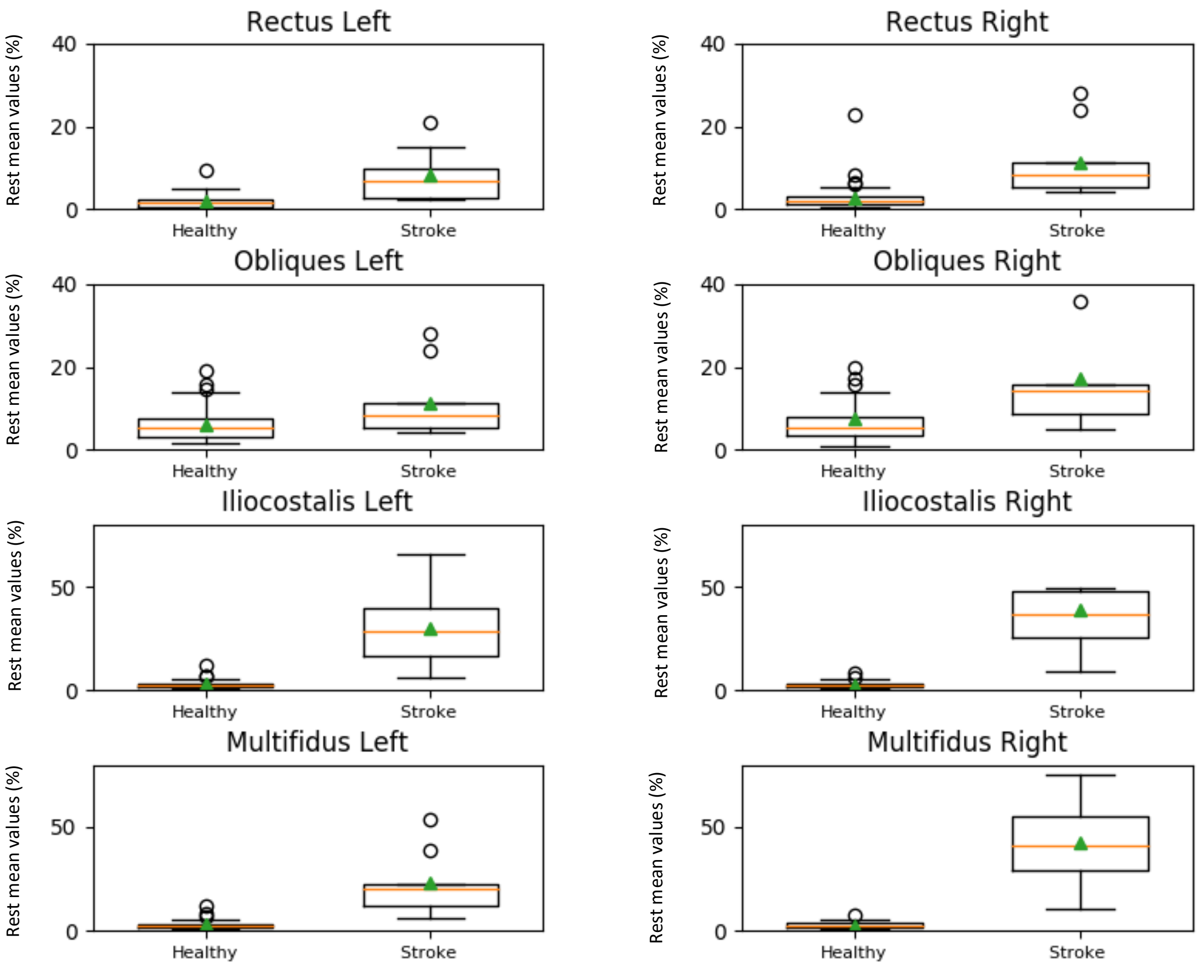


Figure J.1 – Boxplot graphic of mean values of EMG arrays during rest, concerning the two groups studied.

K

Appendix K

In this appendix it will be presented the analysis of EMG frequency for each muscle of both groups of subjects participating in this work.

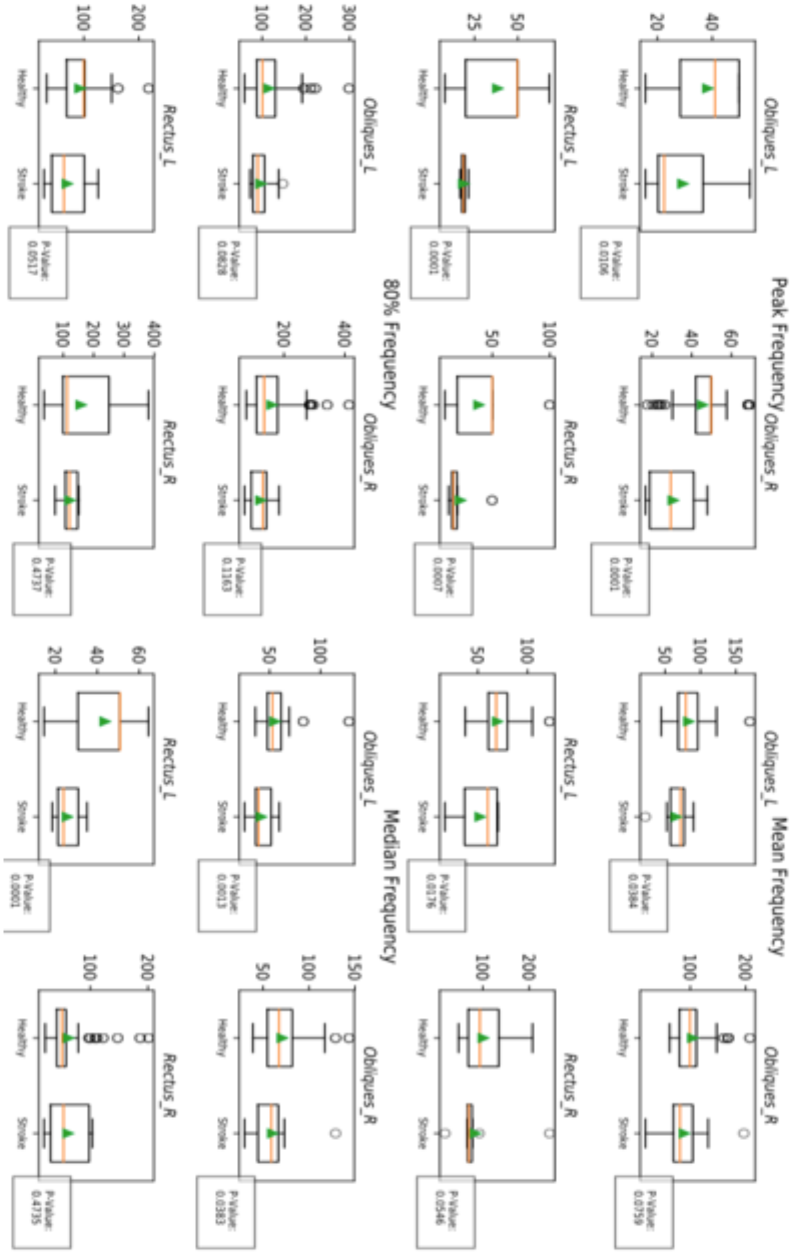


Figure K.1 - Boxplot graphics of EMG frequencies for the anterior trunk muscles, and p-values between the two groups studied., for SEC task.

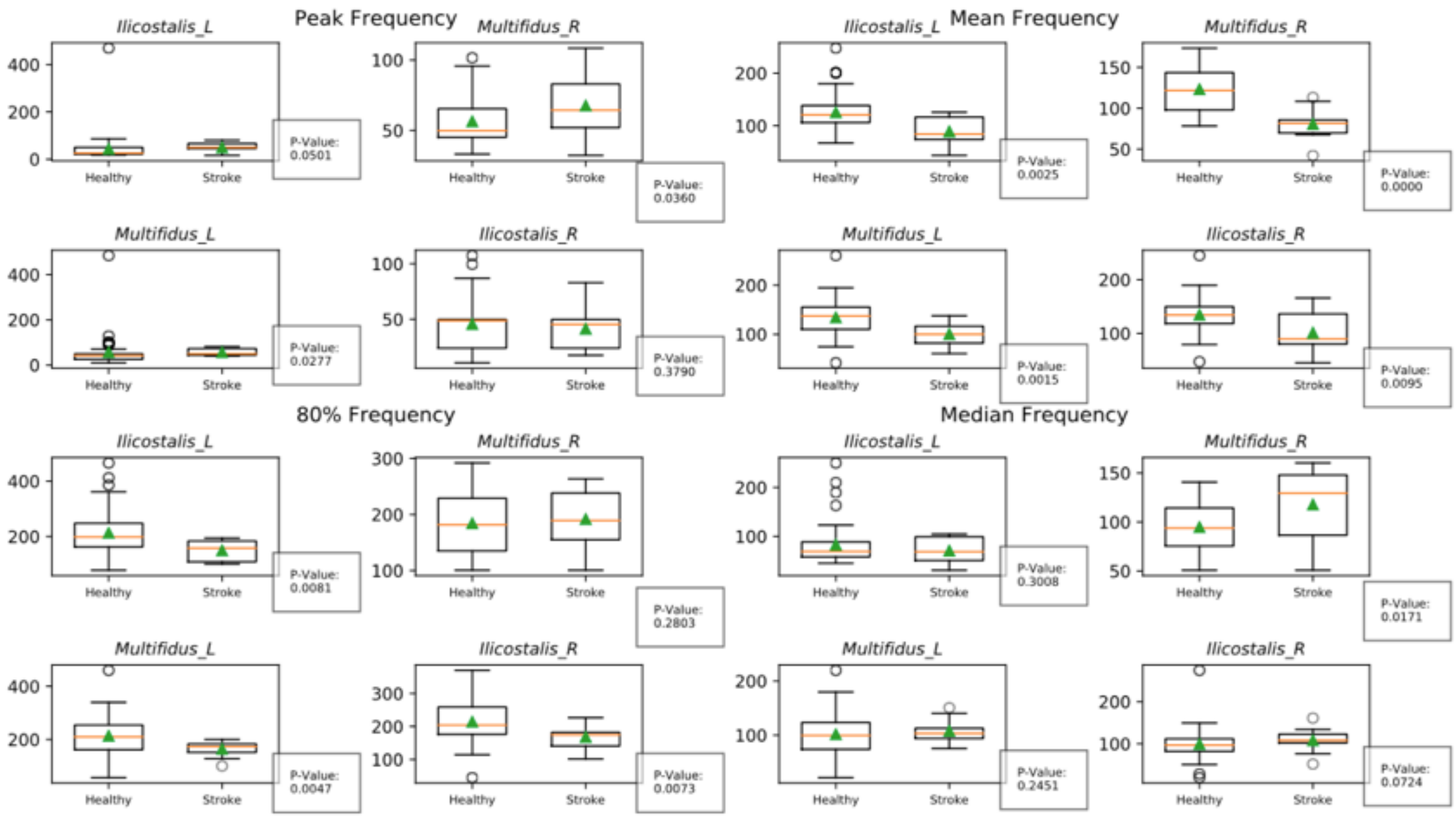


Figure K.2 - Boxplot graphics of EMG frequencies for the posterior trunk muscles, and p-values between the two groups studied., for SEC task.

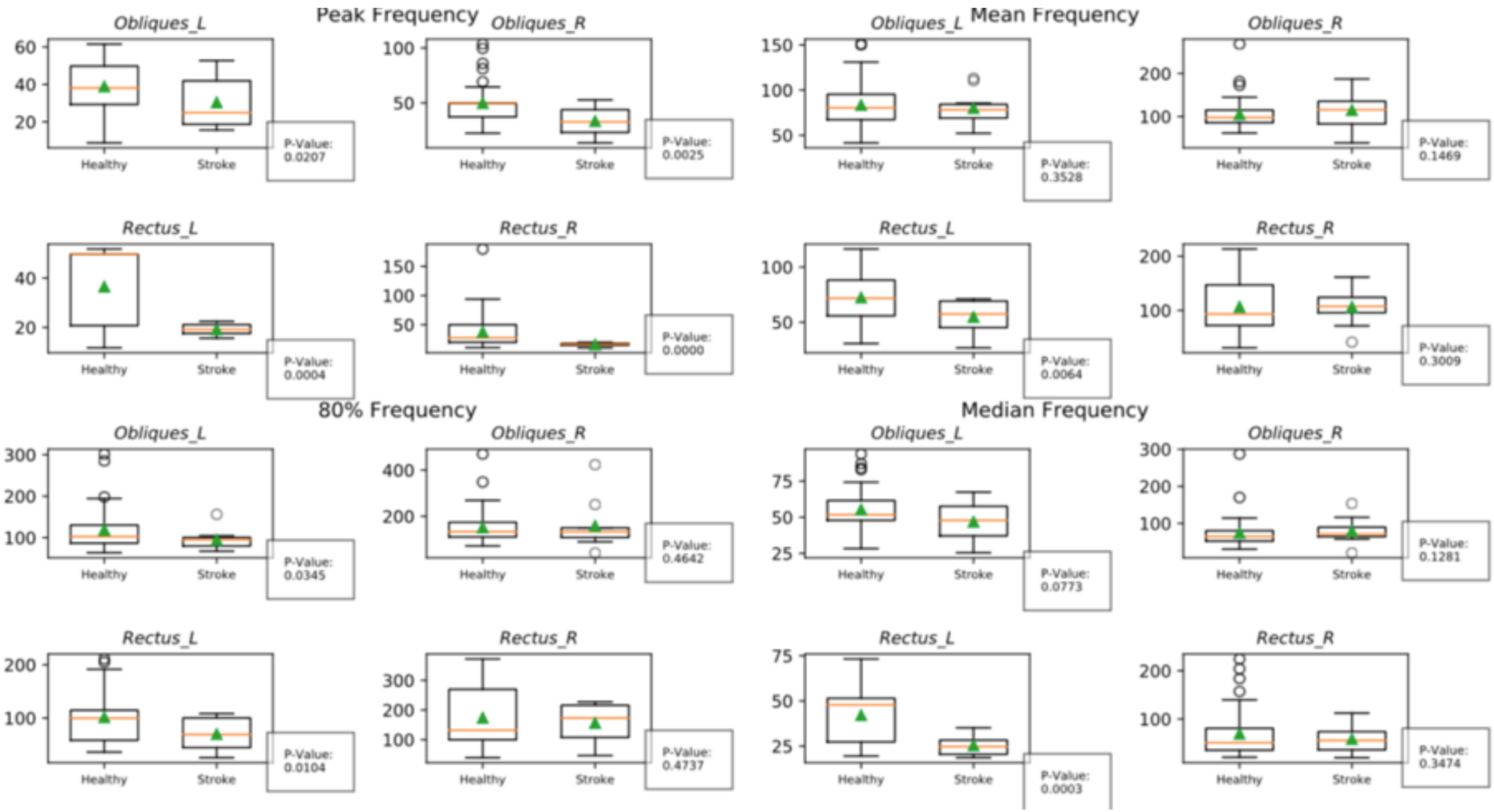


Figure K.3 - Boxplot graphics of EMG frequencies for the anterior trunk muscles, and p-values between the two groups studied., for SEO task.

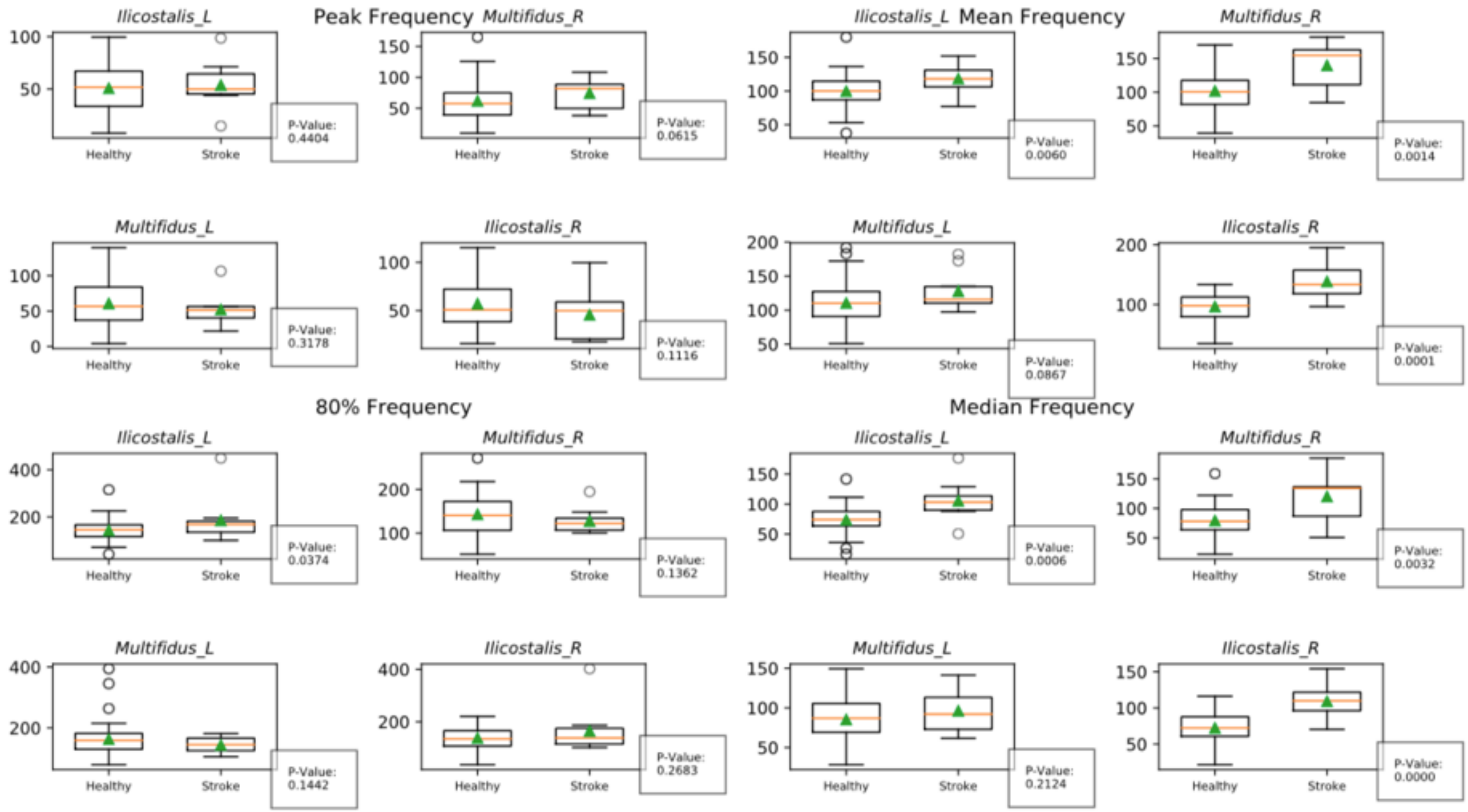


Figure K.4 - Boxplot graphics of EMG frequencies for the posterior trunk muscles, and p-values between the two groups studied., for SEO task.

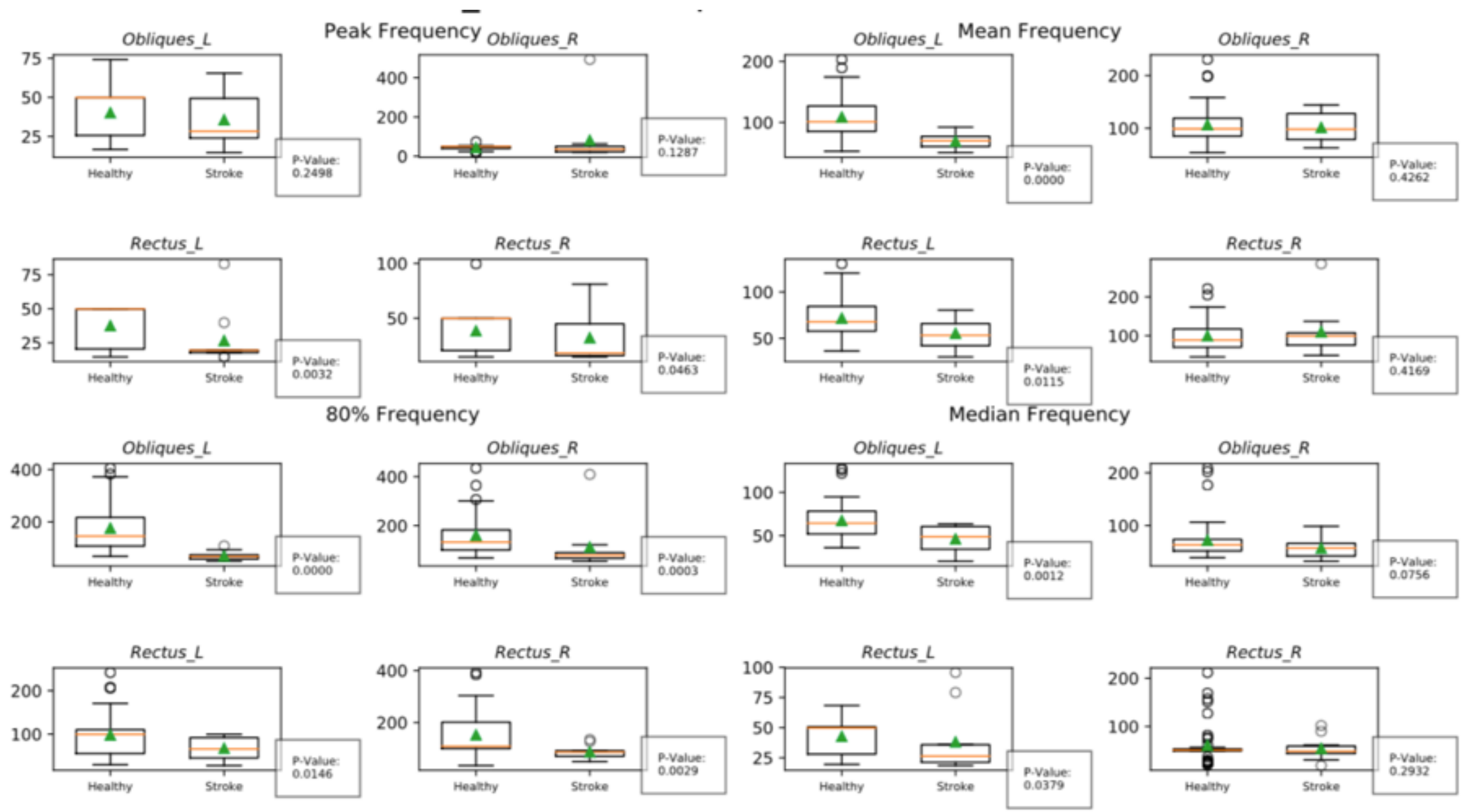


Figure K.5 - Boxplot graphics of EMG frequencies for the anterior trunk muscles, and p-values between the two groups studied., for RR task.

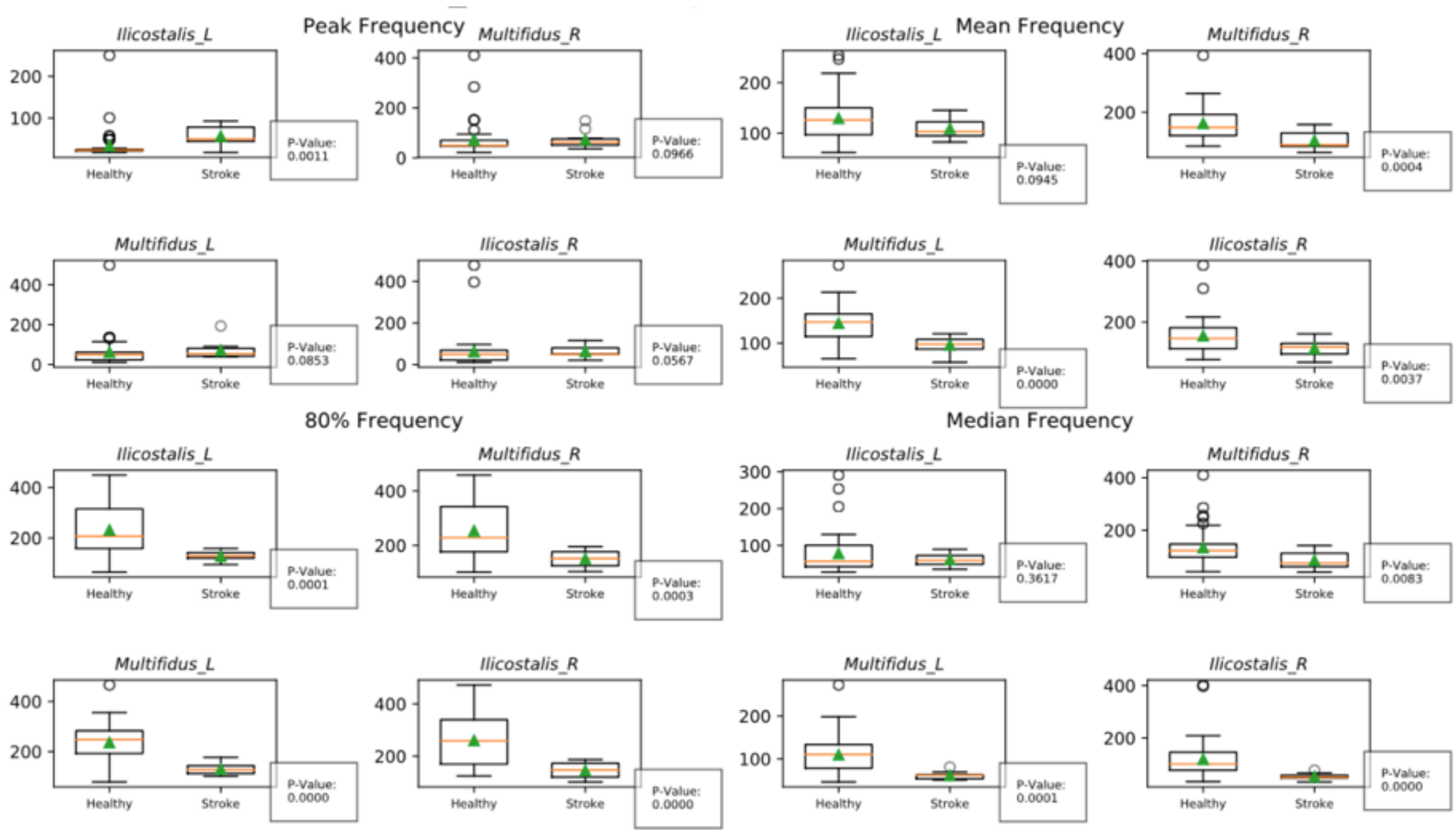


Figure K.6- Boxplot graphics of EMG frequencies for the posterior trunk muscles, and p-values between the two groups studied., for RR task.

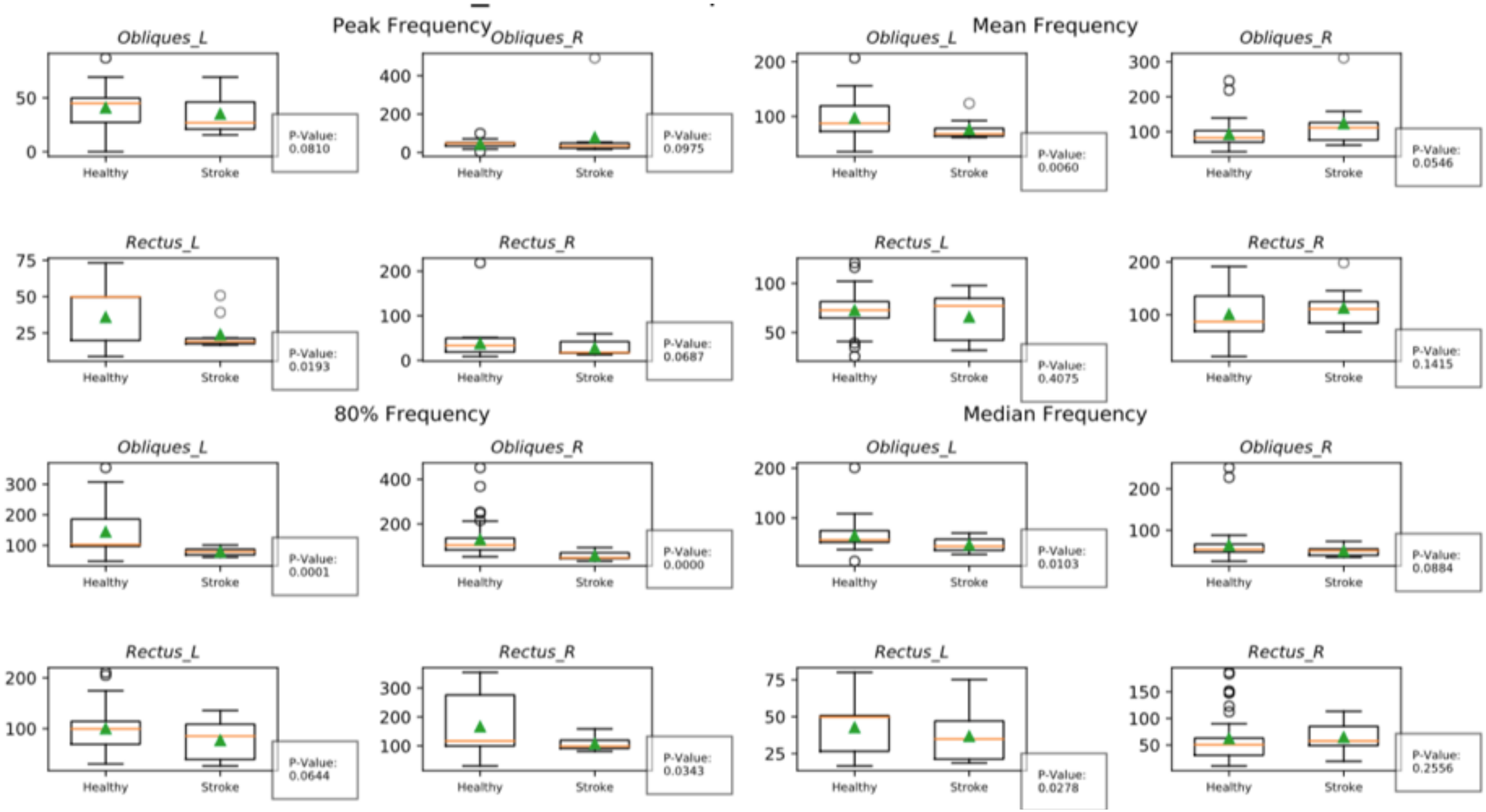


Figure K.7- Boxplot graphics of EMG frequencies for the anterior trunk muscles, and p-values between the two groups studied., for RC task.

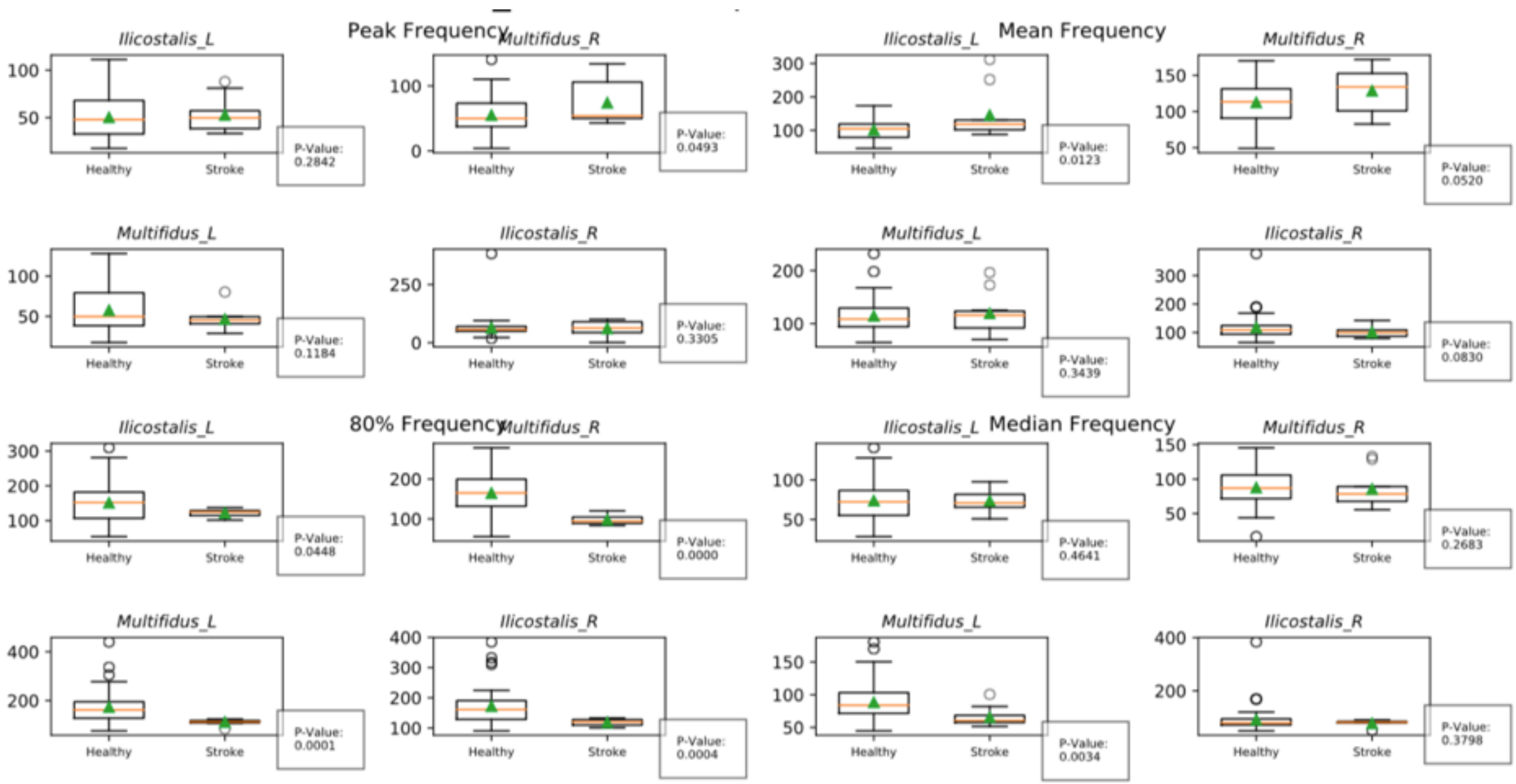


Figure K.8- Boxplot graphics of EMG frequencies for the posterior trunk muscles, and p-values between the two groups studied., for RC task.

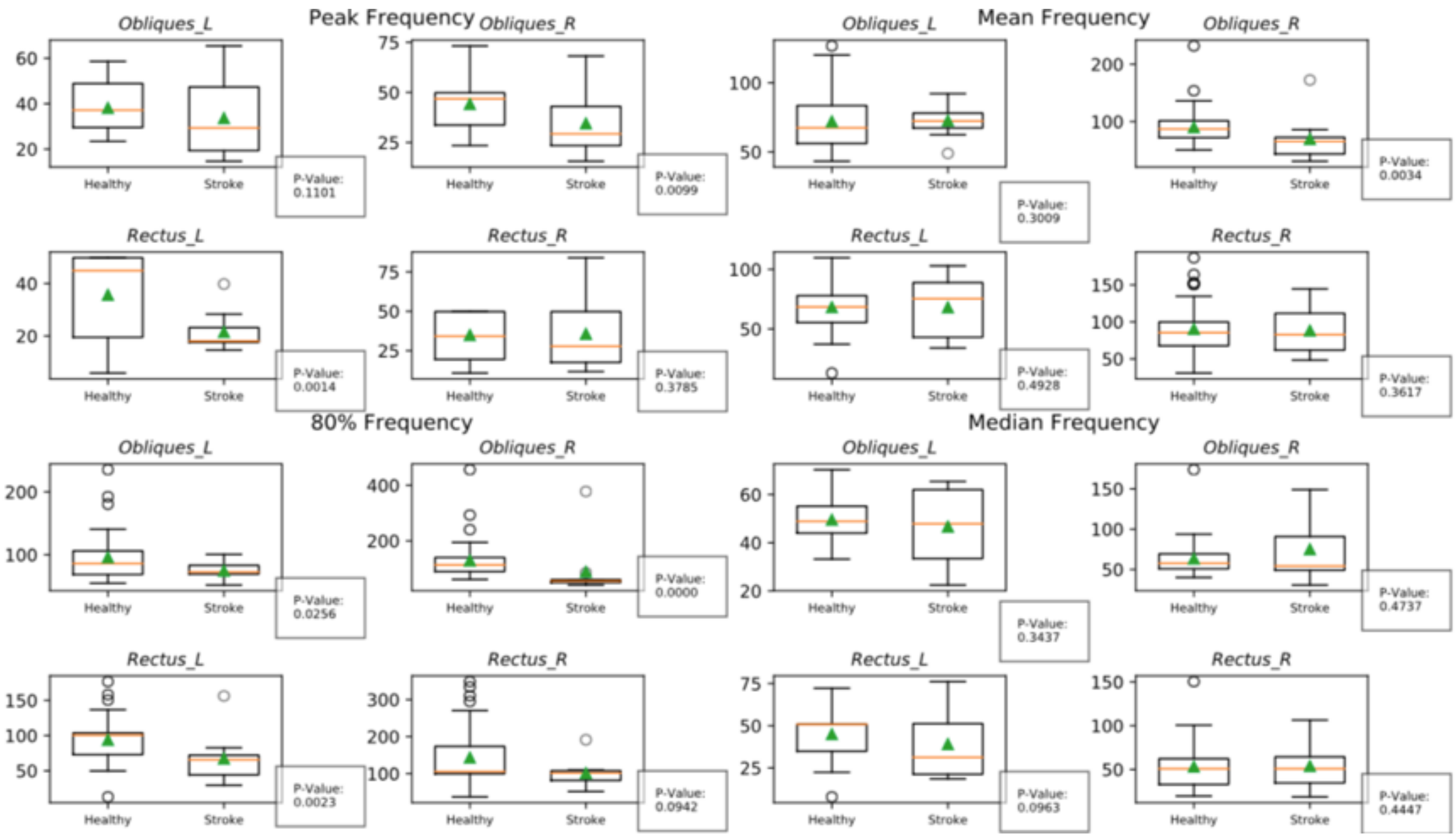


Figure K.9 - Boxplot graphics of EMG frequencies for the anterior trunk muscles, and p-values between the two groups studied., for RL task.

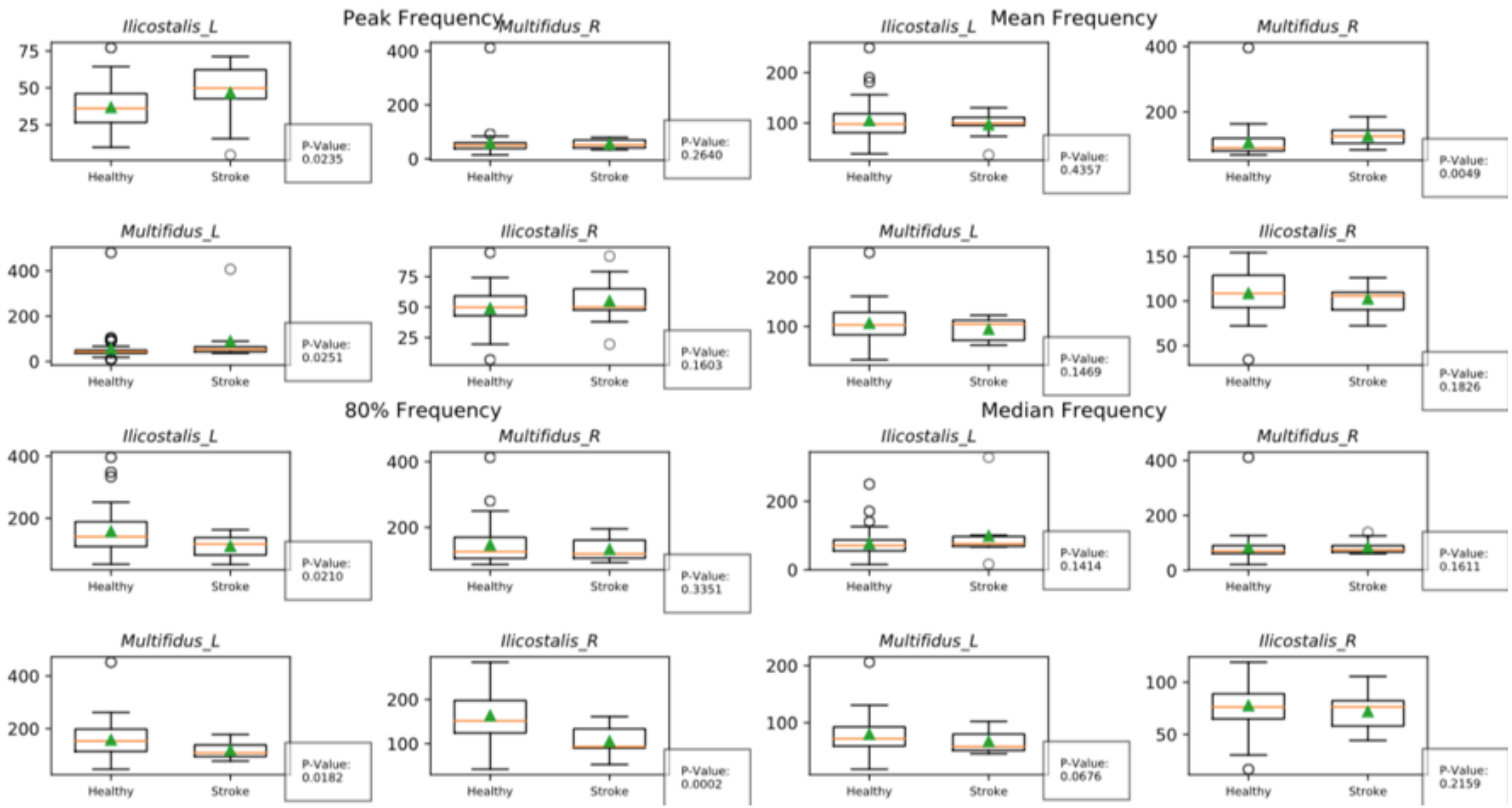


Figure K.10 - Boxplot graphics of EMG frequencies for the posterior trunk muscles, and p-values between the two groups studied., for RL task.

Appendix L

In this appendix it will be presented the analysis of COP parameters and p-values of both groups of subjects participating in this work.

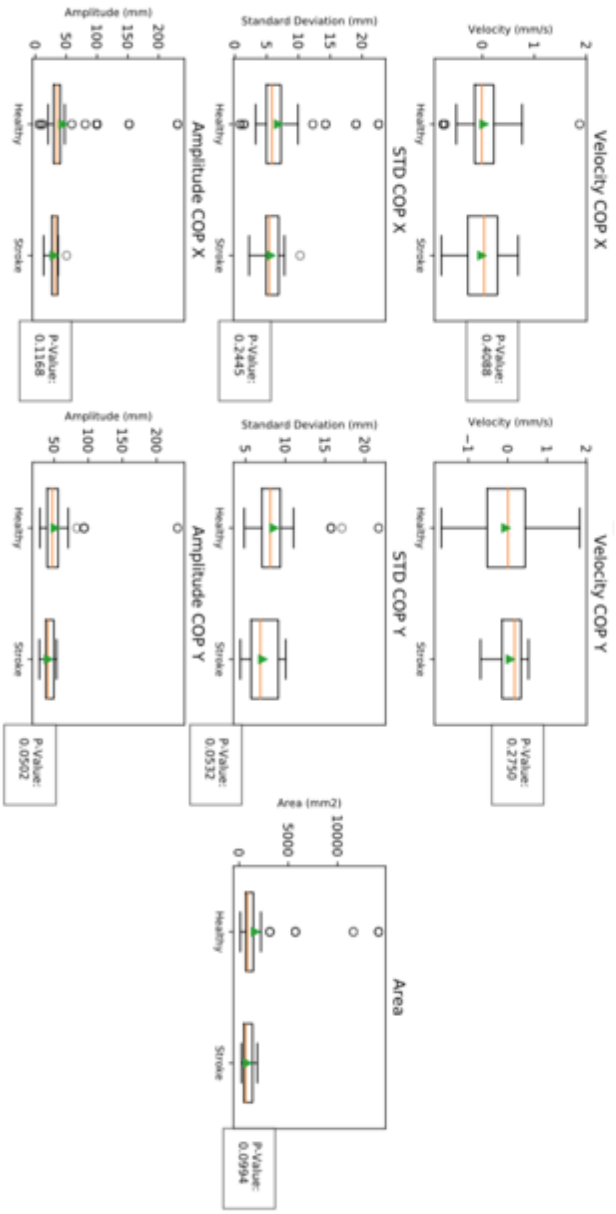


Figure L.1 - Boxplot graphics of COP parameters and p-values between the two groups studied., for SEC task.

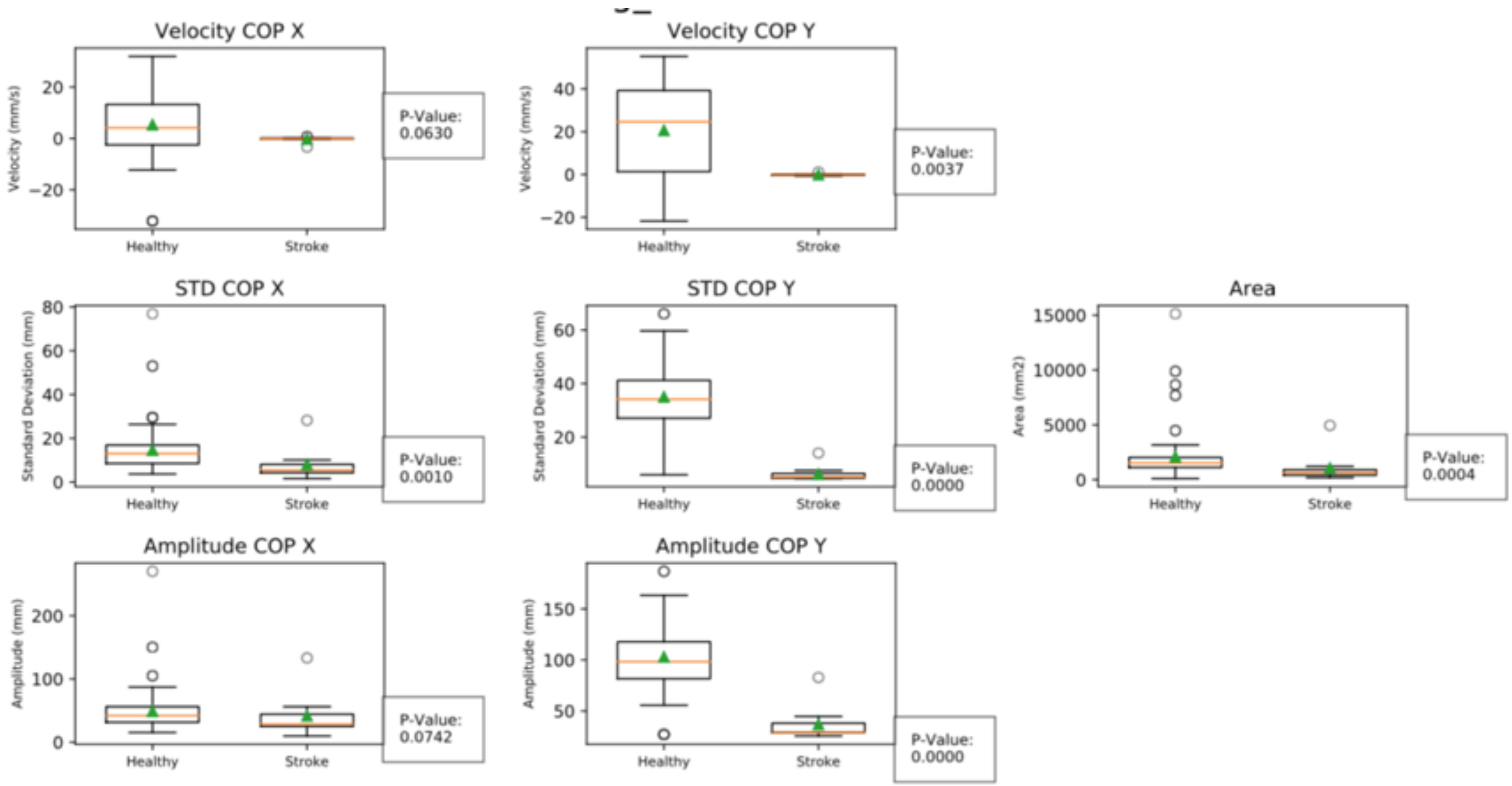


Figure L.2 - Boxplot graphics of COP parameters and p-values between the two groups studied., for SEO task.

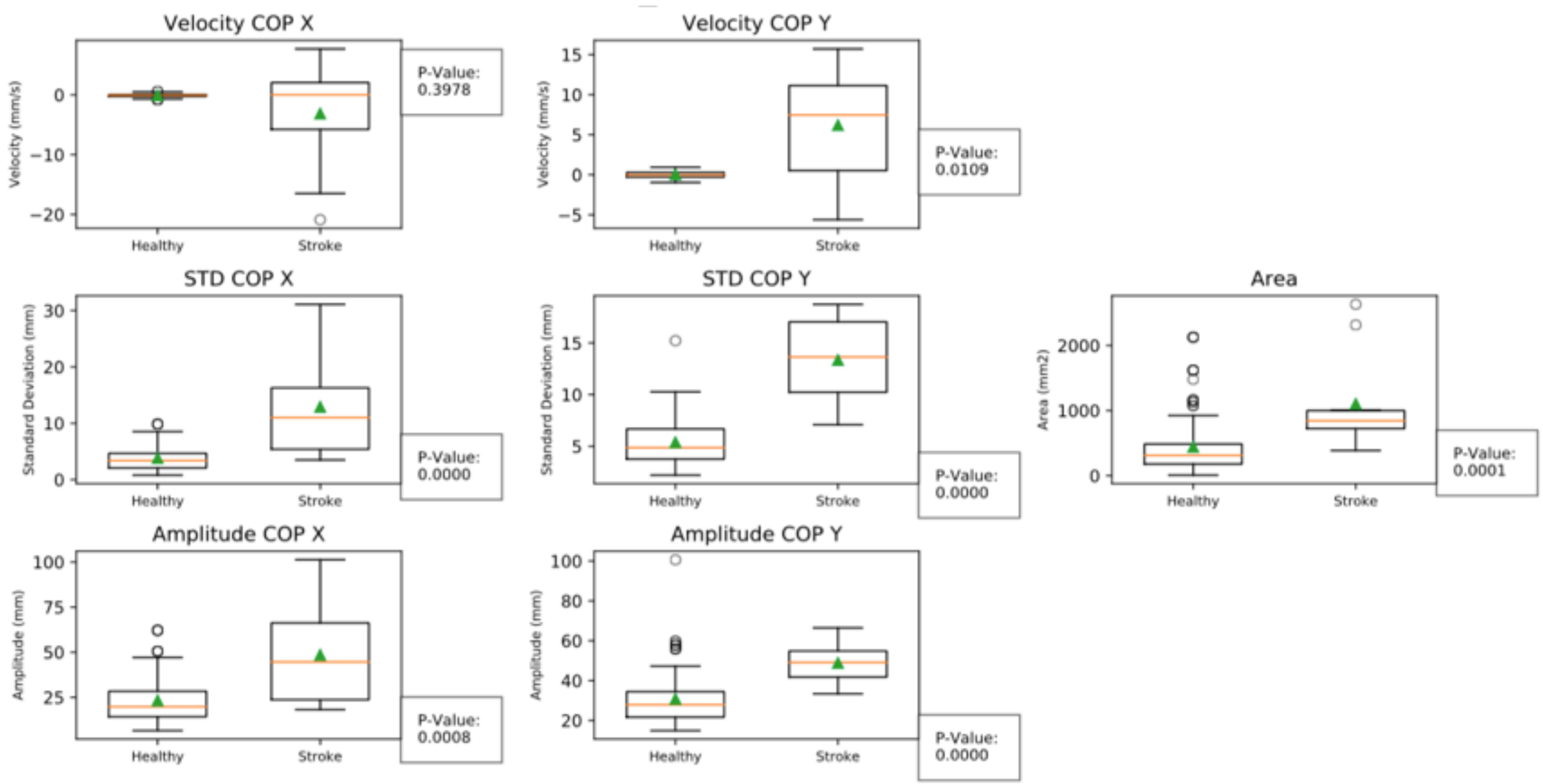


Figure L.3 - Boxplot graphics of COP parameters and p-values between the two groups studied., for RR task.

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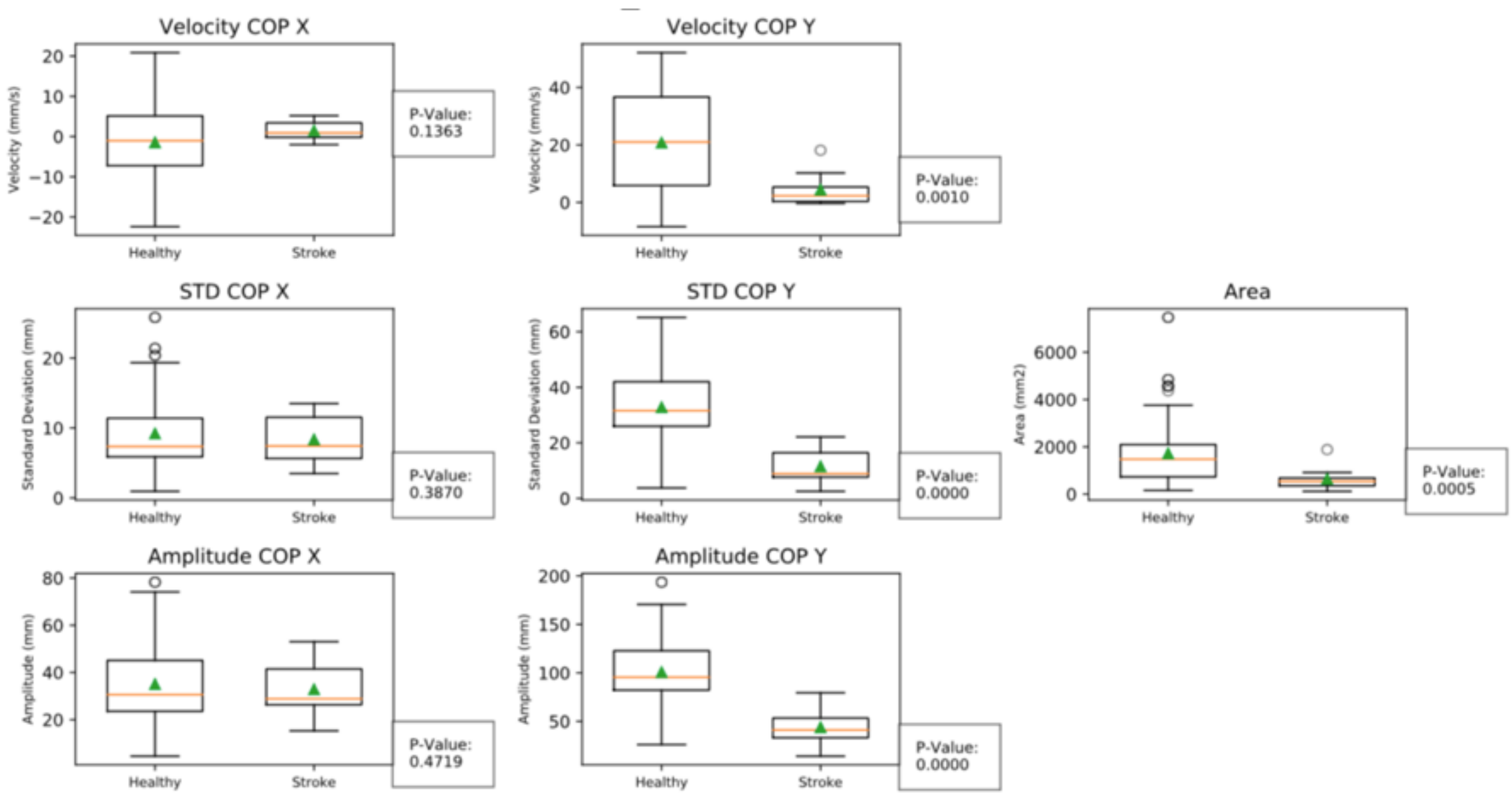


Figure L.4 - Boxplot graphics of COP parameters and p-values between the two groups studied., for RC task.

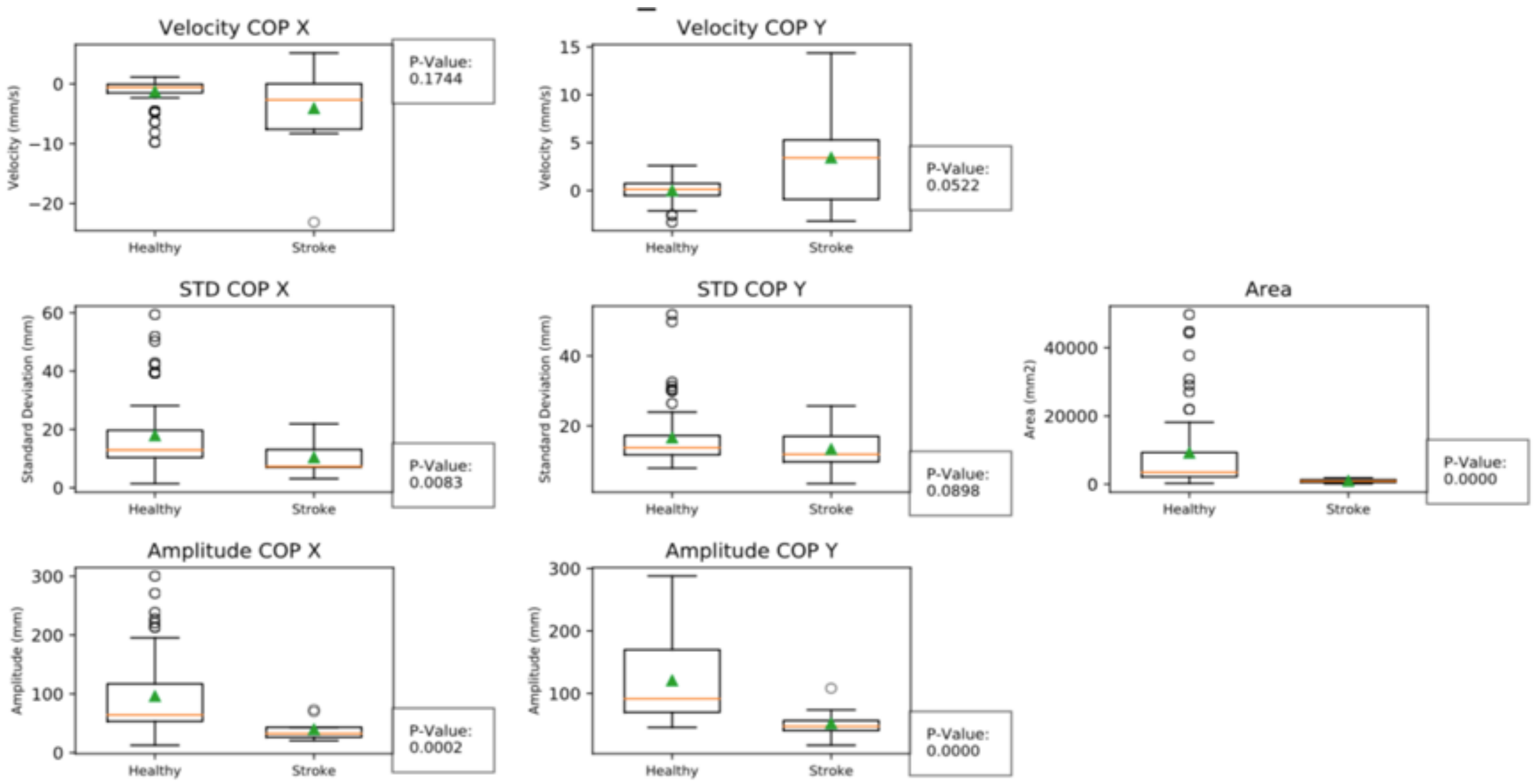
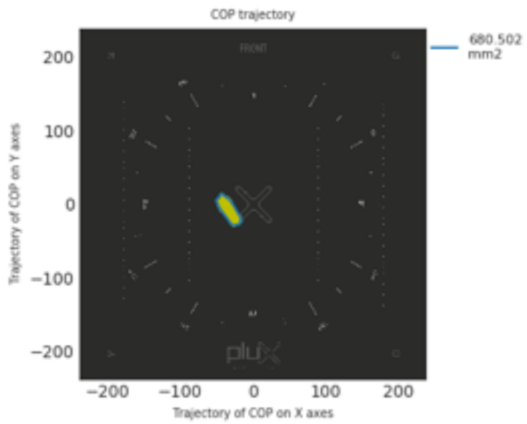


Figure L.5 - Boxplot graphics of COP parameters and p-values between the two groups studied., for RL task.

Appendix M

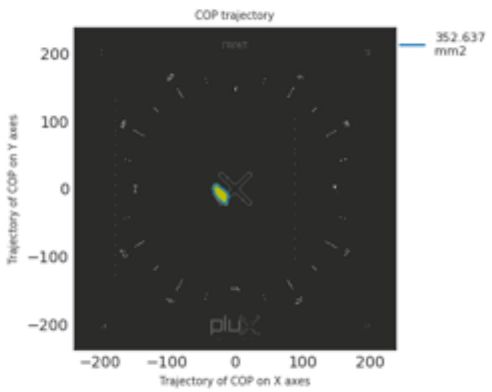
In this appendix it will be presented some individual representations of COP's total area displacement produced in the test and the retest.

1.

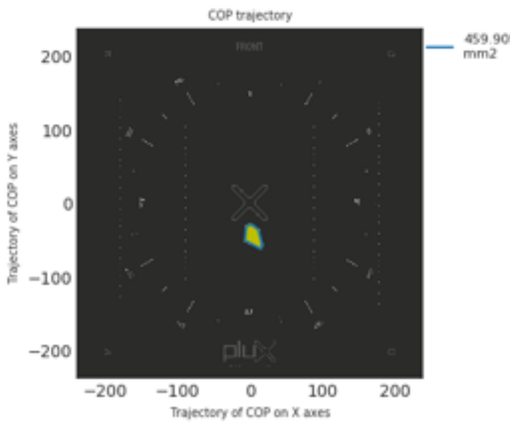


a)

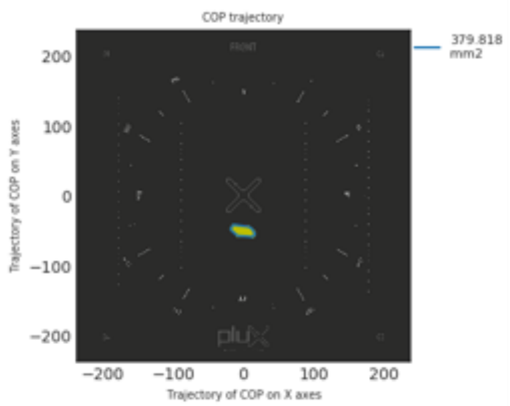
2.



a)



b)



b)

Figure M.1 – Representation of COP total area displacement in a) test and b) retest, for task 1. SEC and 2. SEO, in a stroke patient with right hemiparesis.

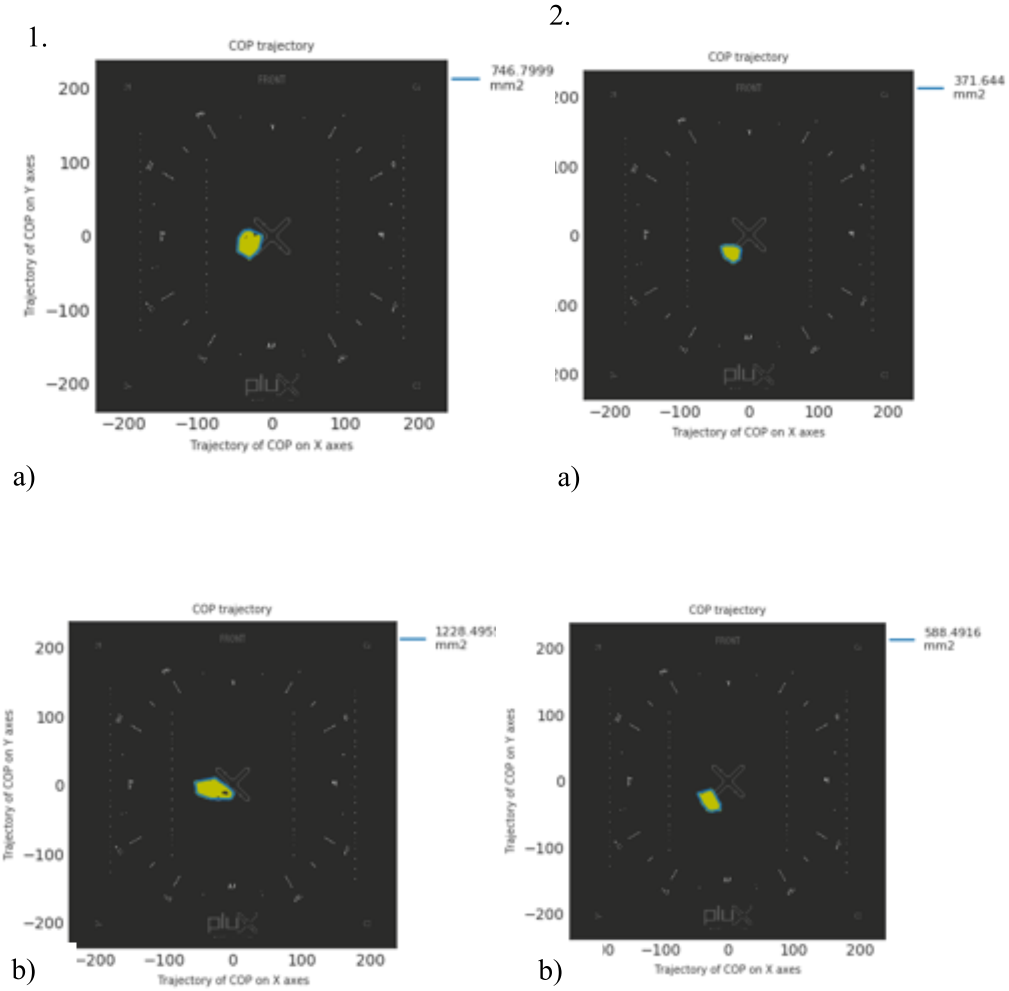
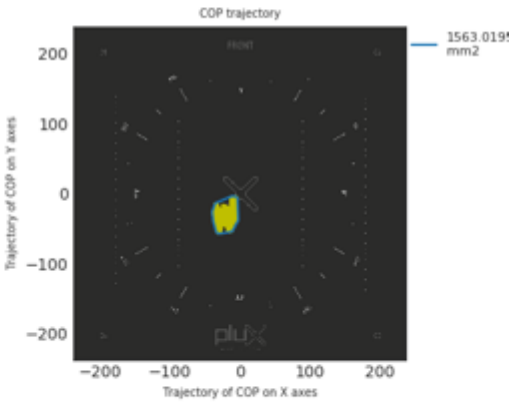
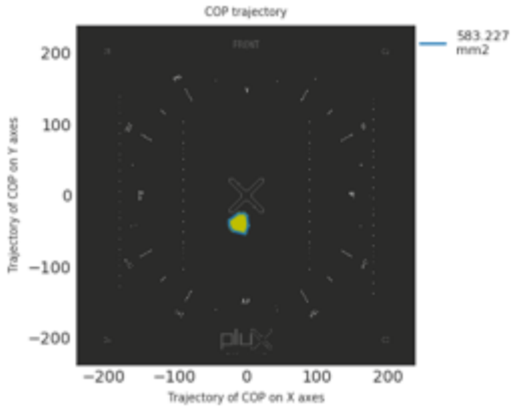


Figure M.2 – Representation of COP total area displacement in a) test and b) retest, for task 1. SEC and 2. SEO, in a stroke patient with right hemiparesis.

1.

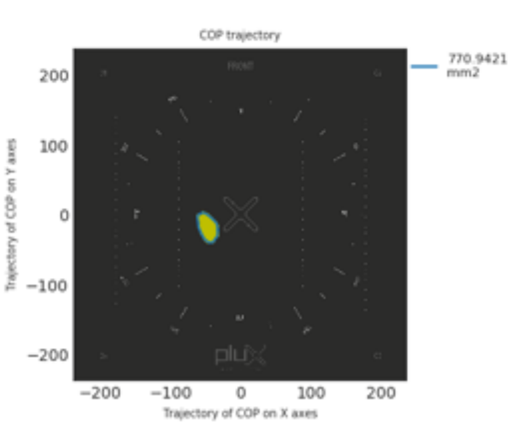


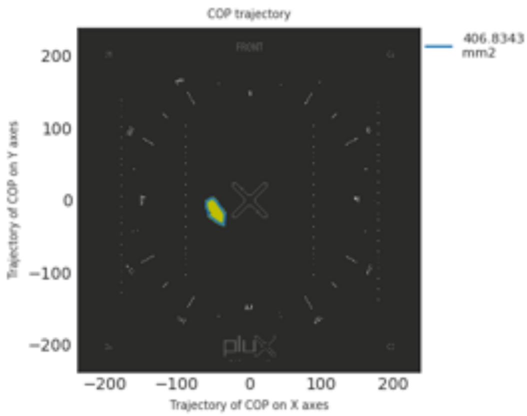
2.



a)

a)





b)

b)

Figure M.3 – Representation of COP total area displacement in a) test and b) retest, for task 1. SEC and 2. SEO, in a stroke patient with right hemiparesis.