Thermal Imaging in Muscle Asymmetry Activity Analysis

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ABSTRACT

Body skin temperature is closely related to the muscle activity due to the thermogenesis caused by physical activity. Human body emits radiation as a way of transferring heat to the environment among other physiological processes, this radiation intensity is directly dependent on the skin surface temperature. Thermography enables us to measure this radiation from the body and accurately transform it in temperature of the skin surface. As well, this muscular activity is supposed to be equal in each contralateral muscle group while realising symmetrical exercises, and to be distinct if the exercise is not realised in a symmetrical way.

The aim of this project is to try to identify any common pattern in the heat distribution variations from a symmetry point of view in two different muscles after the realisation of two distinct weightlifting exercises. These variations are going to be measured with the use of an infrared thermography camera and the software required to the analysis of the pictures obtained during the experiments.

The process followed consists in the realisation of the developed experiment, where the subjects carry out two different exercises, first in a symmetrical way (Both sides with the same load) and then in an asymmetrical way (Different load in each side), after the realisation of each exercise, a thermograph is taken. This method is followed with the intention of comparing the variations while symmetrical exercising and the ones obtained after the realisation of the same exercises in an intentionally asymmetrical way. With these comparisons, it is tried to obtain a relationship between the differences observed in both contralateral muscles and the way of performing the exercise. These relationships could be useful in areas such as elite athleticism, where symmetrical distribution of muscular efforts is related with a better performing, or sports medicine, as asymmetrical exercising could cause different kind of injuries and could derive in the development of some faulty postures like scoliosis.

Results obtained suggests that further experimentation should be done or that the procedure followed was not adequate enough.

Keywords: Thermography, thermal imaging, muscle activity, muscle symmetry.

Contents

1. Introduction

Infrared body heat emission refers to the process of the human body releasing heat in the form of infrared radiation. Infrared radiation is a type of electromagnetic radiation emitted in the range of wavelengths between 780 nm and 1 mm (ICNIRP, 2023) , that makes it invisible to the human eye but can be detected with special equipment or cameras that are sensitive to IR wavelengths.

The human body constantly produces heat through various metabolic processes. This heat is then transferred to the skin, where it can be dissipated through evaporation, convection, conduction, or radiation. Infrared radiation is the primary mode of heat transfer from the human body to the surrounding environment with a percentage of about the 60% of the total (Kuht & D Farmery, 2021).

The amount of infrared radiation emitted by the human body depends on several factors, including body temperature, surface area, and emissivity, which can be defined as the ability of a surface to emit radiation. The skin's emissivity is set by scientists in 0.98 but can vary slightly depending on factors such as skin moisture, texture, and pigmentation. (Ramirez GarciaLuna, Bartlett, Arriaga Caballero, Fraser, & Saiko, 2022)

Infrared body heat emission is commonly used in medical applications such as thermography, which uses IR cameras to measure skin temperature and detect abnormalities in blood flow or tissue inflammation. IR imaging can also be used to detect heat loss from the body, which can be useful in identifying areas of poor circulation or nerve damage. (Ramirez GarciaLuna, Bartlett, Arriaga Caballero, Fraser, & Saiko, 2022)

One of the processes with which the body generates heat is the muscular activity. The contraction and relaxation of the muscles create this heat as a byproduct of the chemical reaction carried out during muscle activity, where ATP molecules are degraded, and energy is obtained. This process receives the name of thermogenesis and the more intense and prolonged the muscle activity, the greater the heat production.

Theoretically, the human body is bilaterally symmetrical, meaning that the left and right sides of the body are practically a mirror. This symmetry is supposed to be observed as well in terms of muscle activity; however, there can be differences between both sides' activity. These differences can be caused by various causes, for example having developed more one side than the other after having practiced specifical sports, being diagnosed with some kind of faulty posture, like scoliosis, or having recovered from an injury. As well, these differences can have consequences, as they can cause an injury due to an overload or decrease the efficiency of the efforts carried out by elite athletes during training and competition.

Adding all together, the aim of this project is to use thermography to try to detect any pattern on the variations on the skin temperature after performing a series of exercises that can ensure that an asymmetrical distribution of the muscle activity is happening.

For that, an experimental study has been performed on two different groups of healthy men between the age of 20 and 29, where they had to complete two gym exercises: biceps curl and bench press. Both, first in a symmetrical way and then in an asymmetrical way, induced by reducing the load on one side by a certain percentage, 10% for the first group and 20% for the second. Thermograms were taking after the performing of each exercise for the posterior analysis of the thermal response in the different stages of the experiment.

2. Theoretical framework

2.1. Human body heat emission

Humans are homeotherm, an organism that can maintain a constant core body temperature, independently of the surrounding environment. Homeothermy allows the correct functioning of the enzymatic reactions that underlies the totality of cellular functions. In the case of humans, the range of temperature that is life-favourable or understood as 'normal temperature' stands between 36.1ºC and 37.5ºC; whilst the range of environmental temperature the naked human body can stand before suffering from hypothermia or hyperthermia is much larger, varying depending on the individuals thermoregulation responses and exposure time. (Wang, Kim, Normoyle, & LLano, 2016).

Human body can be separated into two compartments: Core compartment and peripheral shell. The core compartment refers to the internal organs of the body, while the peripheral shell consists of the skin and subcutaneous fat (Kuht & D Farmery, 2021). These two compartments, transfer heat between each other by a thermoregulation process. In this mechanism, temperature is sensed by the transient receptor potential family of ion channels and the information from the different systems and organs temperature is integrated at distinct levels, finally getting to the main thermoregulatory controller in humans, the hypothalamus (Sessler, 2009).

2.1.1. Heat transfer between core and periphery shell.

Physiological thermoregulation includes processes of heat dissipation and heat generation, depending on the stimuli received. Increases in body temperature induce cutaneous vasodilation and sweating, the cutaneous vasodilation causes an increase in blood flow to the skin and, consequently, increasing the convective heat transfer from the core to the periphery. As a response to the generated sweat, skin temperature decrease, cooling the blood in the dilated vessels before turning back to the core. On the other hand, when exposed to cold environments, a skin blood flow decrease is observed due to a cutaneous vasoconstriction, reducing heat dissipation and the convective heat transfer from the core to the surface. Because of the resulting cooling, shivering appears and causes an increase in the heat generation, helping to maintain the core temperature stabilized (Charkoudian, 2003).

2.1.2. Heat loss between human body and environment

Heat loss or transfer between the human body and the surrounding environment can occur in four different ways: Radiation (transfer of energy by infrared rays from a hotter to a cooler body), evaporation (energy is needed to convert water from liquid state to gas, known as the latent heat of vaporization), convection (transfer of heat thanks to the motion of a gas or liquid across a surface, in this case, the skin), and conduction (heat transfer between molecules in direct contact with each other). From these four ways the human body possesses as heat transferring methods, the one of interest for this thesis is radiation, apart from being the predominant way of heat transfer that occurs on the human body, with an approximated 60% of the heat loss in a naked human in an ambient temperature of 21-25ºC. (Kuht & D Farmery, 2021).

Radiation refers to the loss of heat in form of infrared waves, depending on the wavelength, it can be short-wave radiation, also known as solar radiation, or long-wave radiation, referred as terrestrial radiation. Solar radiation gets to the human body in the form of both visible and infrared radiation, while terrestrial radiation is emitted as a function of temperature and emissivity (Kenny, Warland, Brown, & Gillespie, 2008).

The emissivity of a body refers to its ability to emit thermal radiation, it is a way of measuring the efficiency of the body of interest's heat radiation in the form of electromagnetic waves, in this case, in the infrared range of wavelengths. It can vary between 0 and 1, being 0 the perfect reflective surface, which does not emit any thermal radiation, and 1 the perfect black body, which emits thermal radiation at the highest efficiency, thus, a black body absorbs all incident electromagnetic radiation and emits the 100% of it. For human skin, the value of the emissivity stands at 0.97-0.98 in the long-wave infrared spectrum; thereby, the human body acts as an almost perfect blackbody (Ramirez GarciaLuna, Bartlett, Arriaga Caballero, Fraser, & Saiko, 2022).

2.1.3. Muscle activity and thermogenesis

The term 'muscle activity' refers to the result of the physiological processes that lead to the contraction and exertion of muscles. During this chain of processes, energy is consumed, mostly in the form of adenosine triphosphate (ATP). A division can be made in terms of wilfulness of the muscle activity, distinguishing between voluntary and non-voluntary activity. Each type is controlled by different areas of the nervous system. For this research, the type of muscle activity of interest is the voluntarily controlled one.

Voluntary muscle activity, or contraction, is produced through a series of physiological processes and the coordination of the different systems involved. These processes lead to the intentional contraction of the skeletal muscles to carry out a deliberate movement. This voluntary movement generation can be sequenced in different steps, involving different body systems, which, in combination, produce the mechanical response.

Firstly, the individual makes a decision of the movement required, this takes place on the brain's motor cortex. Then, an electrical signal is generated and transmitted via the motor neurons. When this signal arrives to the neuromuscular junction, it is transformed into a chemical signal thanks to the release of neurotransmitters, which bind to the receptors located on the muscle fibers. Once the neurotransmitters have been bound, filaments of actin and myosin, which compose the muscle fibers, start to slide, causing the shortening of the muscular fiber and, consequently, its contraction. This contraction is then transferred to the tendons, as they are connected to the bones, the desired movement is now carried out. (Pedersen, 2019)

Energy consumption entails an elevation on the metabolic activity and as a by-product of it the production of heat, known as thermogenesis; furthermore, the more prolonged and intense this muscle activity, the higher amount of heat generated. This heat is later conducted through the bloodstream, with the vasodilation it is transferred from the core to the skin, where it can be dissipated into the surrounding environment through the different mechanisms seen before (Kuht & D Farmery, 2021).

2.2. Infrared Thermography

Infrared thermography is the process of using a thermal camera for registering and visualizing the infrared thermal signals emitted by objects' surfaces. Thermography is based on the principle that states that every object with a higher temperature than absolute zero (0K) emits infrared radiation, this principle is known as the Stefan-Boltzmann law (Priego Quesada, 2017); therefore, this radiation is directly related to its temperature. When utilising thermography is also necessary to consider the previously defined concept of objects' emissivity, in order to obtain the most accurate estimation of the surface temperature analysed.

As it measures the surface temperature, in case of the naked human body, thermography is capable of measuring the radiation emitted by the skin in the form of infrared waves and transform it into skin temperature (T_{sk}).

Infrared thermography supposes a non-direct contact way for measuring surface temperature, hence, it is also defined as a non-invasive technique in case of applying it on humans. This, added to the possibilities this technique present, like the ability to visualize surficial thermal maps, makes thermography an ideal mechanism for its use in various areas, from industrial to biomedical purposes (Kylili, Fokaides, Christou, & Kalogirou, 2014).

Thereby, thermography has been used for different purposes on humans. On the available literature it can be seen the use of thermography for thermoregulation study (Vainer, 2005), breast cancer detection (Aweda, Ketiku, Ajekigbe, & Edi, 2010), diagnosis of diabetic neuropathy and vascular disorder (Bharara, Cobb, & Claremont, 2006), fever screening (Nguyen, y otros, 2010); other applications of thermography for medical purposes is shown in the review of Lahiri et al. (Lahiri, Bagavathiappan, Jayakumar, & Philip, 2012).

2.3. Muscle symmetry

Physiologically, the human body presents a mostly general bilateral symmetry regarding the skeletal muscle distribution, normally finding pairs of muscle groups in each side of the body; understanding the division of the body from the frontal axis of it, creating two halves which can be denominated as left and right side of the human body.

Some factors like dominant side, posture habits or injury history can affect this grade of symmetry, causing variations on the size or shape of the muscles in each side, and more importantly on the activity of them. For example, an athlete whose discipline involves the use of one side's muscle more than the contralateral one, will develop more that side and its activity will be higher when analysed. As well, posture habits and injuries can cause muscles imbalances or an alteration in the movement patterns that can also affect to the muscle activity and geometrical symmetry. Therefore, the assessment of muscle symmetry must be considered as an individual process due to the existence of this influential factors. (Fink, Weege, Manning, & Trivers, 2014)

In case of symmetry being supposed to exist in an individual's muscle distribution, both contralateral muscle activity of the same muscle is expected to be the same if the same effort is carried out by both sides, therefore, thermogenesis might be also similar and as an effect of it, the skin temperature variations caused by this heat generation and its following redistribution might also be analogous. However, the perfect symmetry is hard to achieve or be present on humans, and even slight anatomical differences, as well as other factors commented before, could lead to minor asymmetries in muscle activity between contralateral muscles, and as a result to differences in the skin temperature variations caused by the realisation of physical activity.

Some sports or physical activities require the most possible physical and muscle distribution symmetry in order to achieve better results; however, in other sports there is no correlation between muscle distribution symmetry and performance quality, this mostly happens in sports where the use of one side of the body is more required than the other, with the consequent higher development of that side musculature. In literature, some examples can be found. Trivers, et al. showed in their study that symmetry on the lower body of Jamaican elite sprinters was significantly higher than the common population in the same age range (Trivers, et al., 2014); Chudecka et al. showed the existence of significantly higher muscle and skin temperature symmetrical distribution was presented by scullers (symmetrical rowing) than by handball players (Chudecka , Lubkowska, Leznicka, & Krupecki, 2015).

In the case of bodybuilding and weightlifting, symmetrical distribution of muscles and their activity is typically one of the main objectives to achieve, it plays a crucial role in fields like aesthetics, injury prevention and better performance. As a result, developing a method which can assess the level of symmetry while exercising, or after the realisation of it, could entail the improvement towards this fundamental goal.

2.4. Muscles of interest: Anatomy and physiology

Acknowledgement of the anatomy and physiology of the studied muscles, as well as being conscious of which exercises and how to execute them to stimulate their development, is of high importance for this study and for individuals who want to understand better their body and its functioning.

The muscles which are going to be studied are Biceps Brachii (BB) and Pectoralis Major (PM), the selection of them is due to their proximity to the skin surface, no other muscle is closer to the skin, and their minimal relation when realising specifical weightlifting exercises for each one.

2.4.1. Biceps Brachii

Biceps Brachii is a large skeletal muscle located on the front of the upper arm extending from the shoulder to the elbow. It consists of two heads, called long and short heads. Long head has its higher insertion, also called its origin, at the supraglenoid tubercule, located on the glenoid cavity of the scapula. On the other hand, the short head's origin is ubicated at the apex of the coracoid process, a beak-like projection on the scapula. Both heads converge to form a single muscle belly which runs down the humerus and get attached to the radial tuberosity by the insertion tendon. (Myhre & Sifris, 2022)

Figure 1. Anatomical drawing of Biceps Brachii (John the Bodyman, 2014)

Figure 1 is a graphic representation of the anatomy of Biceps Brachii were both heads and insertions are shown.

The main functions or movements created by the contraction of BB are the supination and flexion of the forearm, especially the supination, as the main flexor of the forearm is not the BB but the brachialis muscle, located underneath the Biceps Brachii. BB also has a small role in shoulder flex, as the long head enhance the dynamic stability of the shoulder joint in the first 30º of elevation. Short head of Biceps Brachii also plays an assistive role in the shoulder abduction. (Landin, Thompson, & Jackson, 2017).

2.4.2. Pectoralis Major

Pectoralis Major (PM) is a skeletal muscle located on the anterior surface of the thoracic cage, it is the most superficial of the pectoralis muscles family and is considered to be the main muscle of the chest. Depending on its origin, three parts can be distinguished: Clavicular part (anterior surface of medial half of clavicle), sternocostal part (anterior surface of sternum, costal cartilages of ribs 1-6), and abdominal part (anterior layer of rectus sheath). These three parts converge and insert onto the greater tubercule of humerus.

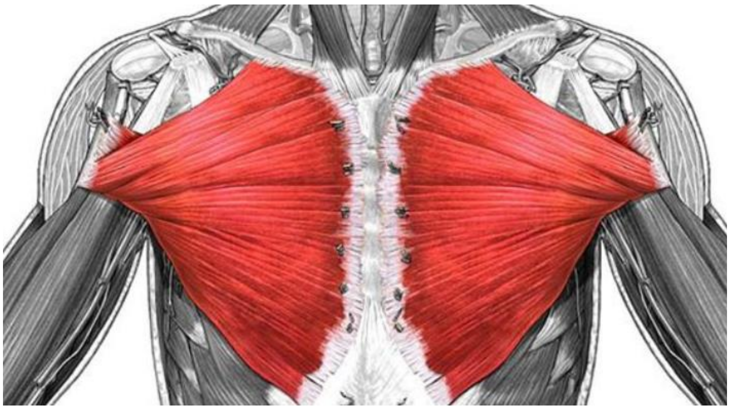

Figure 2. Anatomical drawing of Pectoralis Major (Dream Coloring Magic, s.f.)

Among its functions, PM operates as a strong adductor and internal rotator of the humerus at the shoulder joint while being on anatomical position. As well, the clavicular part is in charge of the flexion of the humerus up to 90 degrees from the vertical axis of the body; whilst the sternocostal portion is responsible of the antagonistic movement, returning the humerus back to the anatomical position.

Furthermore, combined with the Latissimus Dorsi, while its humeral attachment is fixed, PM enables us to pull the trunk forward. It also plays an important role in the shoulder joint stabilization, providing support and keeping a good alignment during a wide range of upper body movements. Lastly, PM helps in deep inspiration by elevating the ribcage and, as a result, expanding the thoracic cavity

3. Material and Methods

3.1. Methods

3.1.1. Laboratory Experiment

The study has been realised over two different groups of men, with different physical characteristics between each other, in order to see if a generalised assessment procedure could be developed. A general methodology was applied to both groups, and only one of the parameters of the experiment was distinct between them. Subjects on both experiments had to perform two different exercises, dumbbell biceps curl and dumbbell bench press, in two different ways, first symmetrically (same load on each side) and after that in an asymmetrical way, where difference in both sides' load is intentionally induced; 10% of the initial load for the first group and 20% for the second group.

First group volunteers presented a mean age of 22.75±2.66 years, mean height of 178±3.84cm, mean weight of 77.45±8.62kg and a mean bodyfat percentage of 18.07±4.31%. As for the second groups of individuals, the mean age was 22.25±0.88 years, mean height of 180.56±9.12cm, mean weight of 79.47±7.72kg and a mean bodyfat percentage of 18.52±3.22%.

The selection of the exercises was made because of the laboratory facilities accessibility and because of the possibility of changing from a symmetrical to an asymmetrical way of performing them.

After each exercise, a thermogram was taken, this way variations in skin temperature can then be compared from one stage to another. With this experiment is tried to show that thermography can be used to assess with certain grade of accuracy if the exercise is being performed in a symmetrical or asymmetrical way. A more detailed description of the different steps of the experiment is below attached.

First, subjects should follow a list of recommendations in terms of obtaining the best results possible when using the infrared thermography camera. Following the standardisation process of B. Zagrodny, with the intention of minimizing the factors which could affect the temperature readings, subjects were advised to try to follow the recommendations shown in Table 1 before the realisation of the experiment (Zagrodny, 2022).

Table 1. Main recommendations of the volunteer preparation (Zagrodny, 2022).

Time before experiment (minimum)	Action
5 days	- Do not sunbath, do not use sauna or cryochamber - Stop using detergents when taking shower - Avoid hot or cold baths
3 days (72 hours)	- Do not use: Creams, lotions, powders, perfumes, deodorants, antiperspirants and other similar substances - Avoid: Physical exercise, intensive physical activity, massage, electrical muscles/nerves stimulation, ultrasound examination, acupuncture, use of warm or cold compresses etc - Remove hair from the study area
1 day (24 hours)	- Do not consume alcohol, - Avoid greasy, spicy meals and or other substances that can improve thermogenesis - Do not use tight clothing items
12 hours	- Last bath: a short shower in lukewarm water without detergents
4 hours	- Avoid physical exertion (quick gait, run, stairs climbing to higher floors, exercises) - Do not consume drinks with caffeine (including strong tea), hot or cold drinks - Last meal, avoid high caloric one
2 hours	- Do not eat, but avoid experiment on empty stomach

Regarding the previous preparation of the laboratory conditions, we also take into consideration the recommendations given by B. Zagrodny in his work about standardization procedure of infrared imaging in biomechanics (Zagrodny, 2022), this way the following steps shown in Table 2 for its conditioning were tried to be followed at every laboratory session.

Table 2. Main recommendations for the laboratory preparation (Zagrodny, 2022).

Time before experiment (minimum)	Action
2 days (48h)	- Stabilise: Temperature in rage 21ºC-24ºC Real humidity in range 40-55%
1 day (24h)	- Remove all IR raditors (if temperature is higher than 10ºC than temperature in the laboratory) - Cover unmovable IR radiators
In a day of experiment	- Reduce to the possible minimum: Convection, advection - Use window blinds to reduce the external IR radiation - Do not use ventilators, AC or similar equipment which can change the temperature or RH rapidly or causes an intensive air movement

Once the previous preparation of both the subjects and the laboratory conditions has been carried out, the experiment can be performed.

It consists of different stages, all of them were common for both of the studied groups, just one parameter was changed: the load difference in percentage when performing the asymmetrical exercise.

First, subjects had to get undressed, keeping the lower limbs clothes on if wanted, as the study doesn't focus on this area. They must be at least 15 minutes, which is the minimal adaptation time required, during this time subjects must maintain in a relaxed way, avoiding touching the areas of interest for the study for reducing the factors that would alter the skin temperature (Garagiola & Giani, 1990).

Once this accommodation time has passed, the first thermal image is taken, this way the skin temperature at an initial stage, which can also be named as repose stage, can be measured. The thermogram is taken the same way throughout the different stages of the experiment, the IR camera is located three metres away from the subject, who stays on anatomical position during the thermogram taking. For every stage, two thermograms are taken, in order to average the temperature measured in both thermograms and for having less chances of having an erroneous measurement which would cause the repetition of experiment, as these mistakes are just observable on the post-processing of the thermograms.

After the thermograms have been taken, the subject must perform the first exercise of the experiment. As we just focus on the Biceps Brachii and Pectoralis Major, dumbbell biceps curl was chosen as the first exercise, due to its relatively easy realisation with a good technique and the materials accessibility at the laboratory. The exercise consisted of repeating in a standing position with similar weight load in both sides until what in the field of weightlifting is usually named as failure, meaning the subject has gotten to the point of muscular fatigue and exhaustion, therefore, they can no longer perform the movement with the desired range of motion and control. Training to failure means muscles are working at their maximum capacity, hence, it requires a high level of energy expenditure, what leads to an increase in the metabolic rate and in thermogenesis by the exercised muscle. The weight was chosen individually for each volunteer, so the subject could repeat at least 15 times.

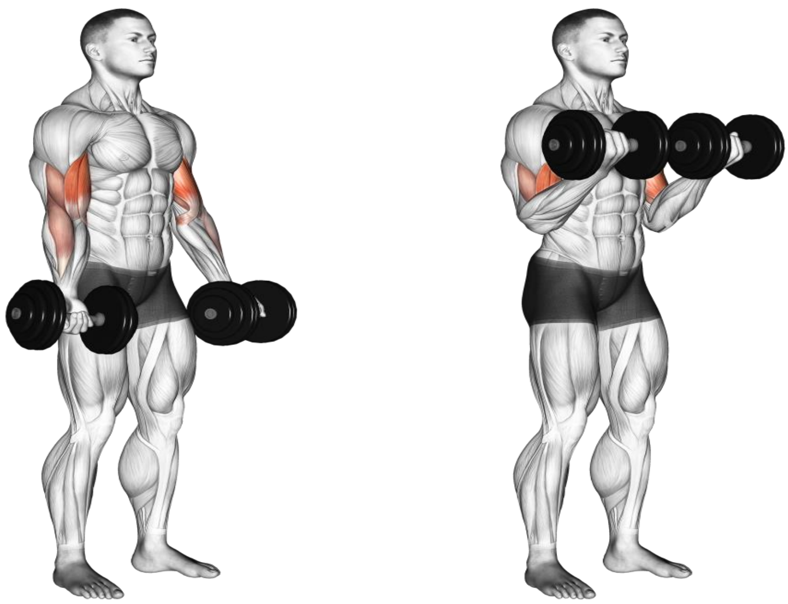

Figure 3. Graphical representation of dumbbell bicep curl (Luna, 2023).

Afterwards, subjects waited around five minutes, while resting in a relaxed position and again without making any kind of contact in the studied areas, after that, the second thermogram was taken, again twice for the same reasons as the first one.

Just after the capturing of the thermogram subjects performed the second exercise of the experiment. This time, symmetrical dumbbell bench press, to stimulate the Pectoralis Major. Similar procedure was followed as in the biceps curl, weight was selected so that subjects could repeat at least 15 times until failure. Once again, subjects rested for five minutes before the third thermogram was taken.

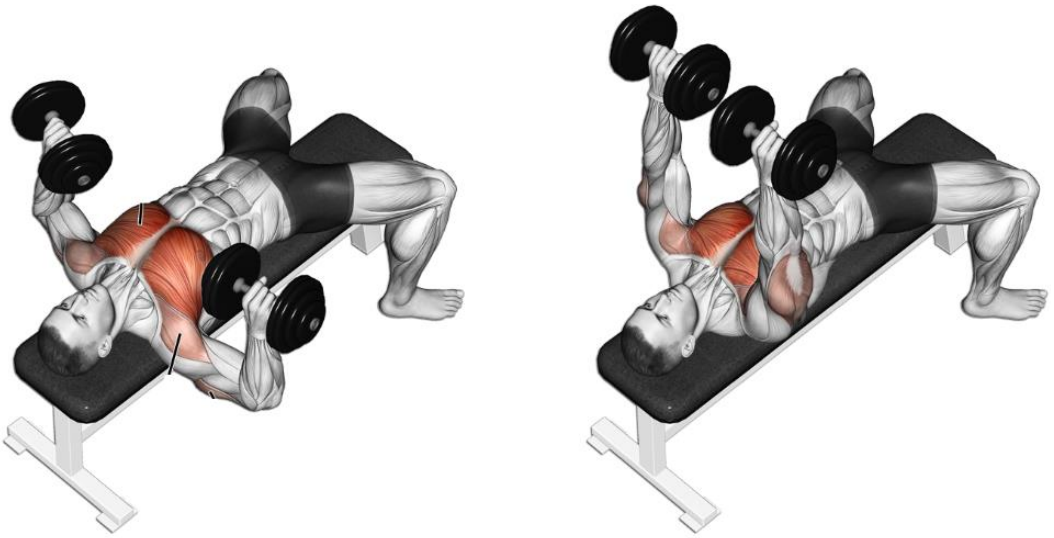

Figure 4. Graphical representation of dumbbell bench press (bpeacebart, s.f.).

At this point of the experiment, what can be called the 'symmetrical part of it' is finished, so differences in T_{sk} can be assessed after the realisation of symmetrical exercises, which theoretically should not lead to significant differences between both sides.

Now, the experiment enters the 'asymmetrical part', where different loads are lifted by the subjects. In the same way, after the thermogram capturing, subjects performed the third exercise: asymmetrical dumbbell biceps curl. The differences in each side load were 10% of the initial load (Load on the symmetrical exercise) for the first group and 20% for the other one. Initial load was kept constant on the left side, and a lower weight was lifted by the right side. This time, the failure was determined when one side can no longer repeat once more. After the performing of the workout and the respective five minutes of rest, the fourth thermogram was taken.

Afterwards, the final exercise is carried out. This time, asymmetrical dumbbell bench press, keeping the initial load on the right side and reducing the load on the left one. After the performing and the resting time, the fifth and final thermogram is taken.

With this last thermogram taken, the experiment part is concluded.

3.1.2. Volunteer data collecting

After the realisation of the experiment. Height, weight, and body fat percentage was measured for all subjects on the laboratory. As well, injury history and observations about anatomical deficiencies, like faulty postures and body asymmetry, were made.

All this was made for the statistical analysis of the subjects' sample and for possible explanations of future abnormal results of the measurements.

3.1.3. Thermograms analysis

After having taken the different thermograms in the laboratory, the post-processing stage, using a suitable software program, could start.

First, an individual segmentation must be done on each thermogram. They were manual and it was tried to make them the most similar for both sides as possible; as well as the most reliable as possible, considering both the standard and the subject's individual anatomy. This way four studied areas were created for each thermogram, one for each muscle of interest. The software enables us to measure different parameters for each delimited area; on this study, we paid attention on three of them: Average Temperature (T_{AVG}), Maximal Temperature (T_{MAX}), and Minimal Temperature (T_{MIN}). All the measurements were then collected for its posterior analysis.

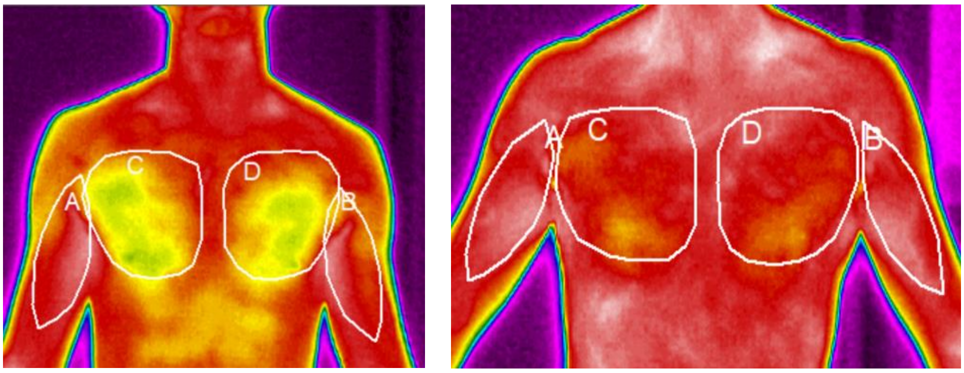

Figure 5. Examples of two different manual segmentations done for the thermograms analysis

Figure 5 shows two examples of the manual segmentations which were made for the analysis of the region of interest in the thermograms collected.

3.2. Materials

The materials used in the laboratory for the experimental and the volunteer data collecting parts of the study were:

- InfraRed Camera: NEC-Avio R300SR (NEC, Japan)
- Regulable dumbbell set
- Gym bench
- Skinfold calliper: Harpender Batty
- Scale: Radwag (Poland)
- Scoliometer

As for the processing stage, the software used for the segmentations and measurements was 'InfReC Analyzer NS9500 Standard' as well as the user manual of the program. Once the measurements were done, the analysis of the variations between stages was made using Excel, where mathematical and graphical processes were carried out.

4. Results

As commented in the methods section, three parameters were measured for each muscle of interest on each thermogram: T_{AVG}, T_{MAX}, T_{MIN}.

For the results' analysis the different parameters at every stage of the experiment were averaged between all volunteers of each group, understanding these followed a peaked distribution, in which the bigger probability density is around the mean value. As the sample size is reduced to just eight individuals per group, this cannot be ensured or demonstrated plotting the histogram, so this is a supposition to facilitate the study.

After collecting all the needed data, the following results were obtained to try to fulfil the objectives of the thesis.

4.1. Experiment with 10% load difference on the asymmetrical exercises.

T_{AVG}, T_{MAX}, T_{MIN} were averaged in the different steps of the laboratory experiment between the eight volunteers of the first group, for both the left and right BB and PM.

When averaged, the left side's values were subtracted from the right side's values, and the average differences between collateral muscles ΔT_{AVG}, ΔT_{MAX}, ΔT_{MIN} were obtained. This can be seen in Equation 1.

$$\Delta T = T_{Right} - T_{Left} \tag{1}$$

- Results for Biceps Brachii

Table 3. Values for averaged ΔT_{AVG}, STD and ΔT_{AVG} ±STD values in the different stages of the experiment for BB in the 10% load difference experiment.

Stage of experiment	ΔT_{AVG} in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.0419	0.1620	0.2038	-0.1201
After Symmetrical Biceps Curl	0.0513	0.2148	0.2661	-0.1636
After Symmetrical Bench Press	0.0525	0.2770	0.3295	-0.2245
After Asymmetrical Biceps Curl	0.0500	0.2354	0.2854	-0.1854
After Asymmetrical Bench Press	-0.0006	0.2323	0.2317	-0.2329

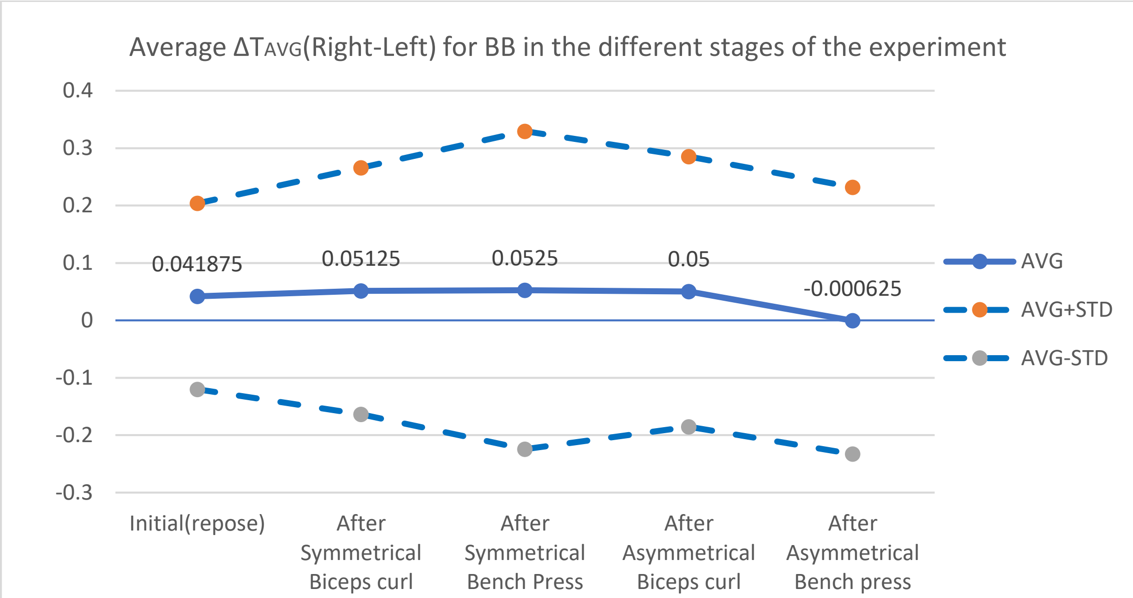

Figure 6. Chart of averaged ΔT_{AVG} values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 10% load difference experiment.

It can be seen in Figure 6 and Table 3 the values of the averaged ΔT_{AVG} for BB in the different stages of the experiment. It is observable that the differences between right and left side do not practically vary throughout the different stages. As well, all values turn to show both negative and positive values, due to the averaged value is, in all stages, close to zero and STDs are large enough to show these alterations below and above zero.

Table 4. Values for averaged ΔT_{MAX}, STD and ΔT_{MAX} ±STD values in the different stages of the experiment for BB in the 10% load difference experiment.

Stage of Experiment	ΔT_{MAX} in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.0488	0.2757	0.3244	-0.2269
After Symmetrical Biceps Curl	0.0544	0.4107	0.4651	-0.3563
After Symmetrical Bench Press	0.0425	0.4399	0.4824	-0.3974
After Asymmetrical Biceps Curl	0.0700	0.1746	0.2446	-0.1046
After Asymmetrical Bench Press	-0.1038	0.5391	0.4354	-0.6429

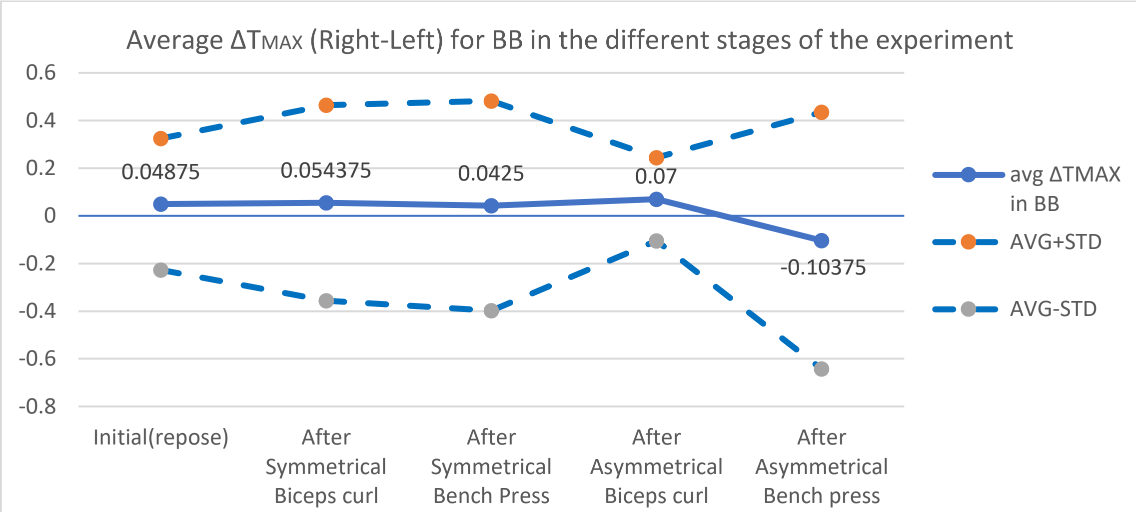

Figure 7. Chart of averaged ΔT_{MAX} values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 10% load difference experiment.

As it happened with the ΔT_{AVG} values, in Table 4 and Figure 7 a practically non variance in ΔT_{MAX} values is observable, with the exception of the last experiment stage; however, this shouldn't be determinant for the Biceps Brachii analysis as it corresponds to the Pectoralis Major exercising when bench pressing.

As well, fluctuations between positive and negative values can be observed with the AVG±STD margin representation on Figure 7.

Table 5. Values for averaged ΔT_{MIN}, STD and ΔT_{MIN} ±STD values in the different stages of the experiment for BB in the 10% load difference experiment.

Stage of experiment	ΔT_{MIN} in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	-0.1713	0.4064	0.2351	-0.5776
After Symmetrical Biceps Curl	-0.0438	0.5027	0.4590	-0.5465
After Symmetrical Bench Press	-0.0750	0.6760	0.6010	-0.7510
After Asymmetrical Biceps Curl	0.0456	0.5912	0.6368	-0.5456
After Asymmetrical Bench Press	-0.1400	0.7246	0.5846	-0.8646

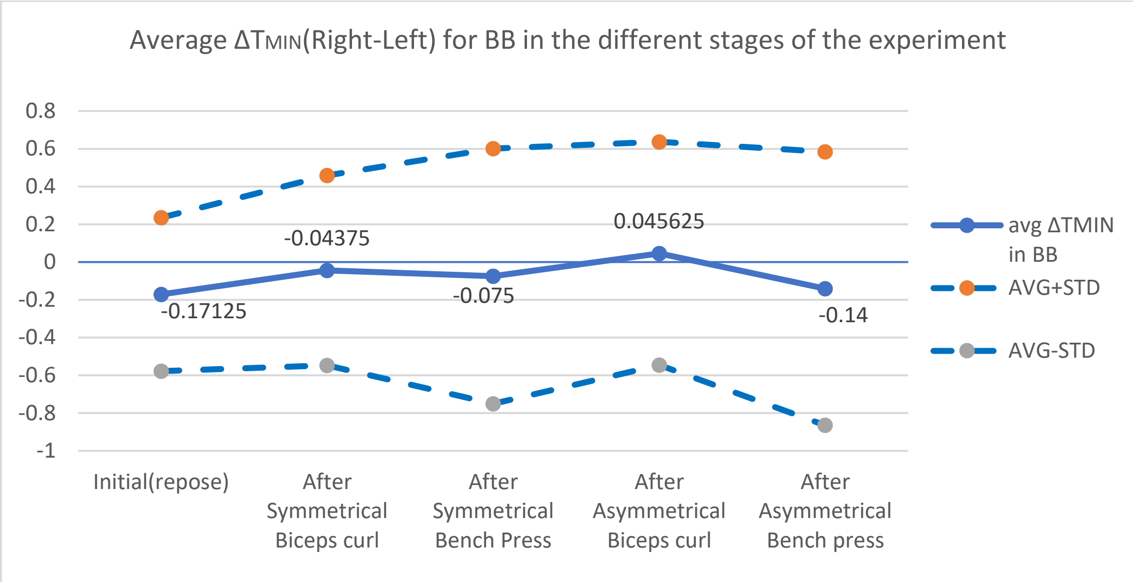

Figure 8. Chart of averaged ΔT_{MIN} values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 10% load difference experiment.

In Table 5 and Figure 8, the different values for ΔT_{MIN} are shown and charted. In difference with the other to ΔT parameters measured, ΔT_{MIN} show higher variation through the different stages. After the performing of both symmetrical and asymmetrical biceps curl, a slight increase in ΔT_{MIN} is observable, meaning that in both cases the T_{MIN} of right-side Biceps Brachii experiment a slightly lower temperature decrease comparing it with the left-side Biceps Brachii. This is shown in Figure 9.

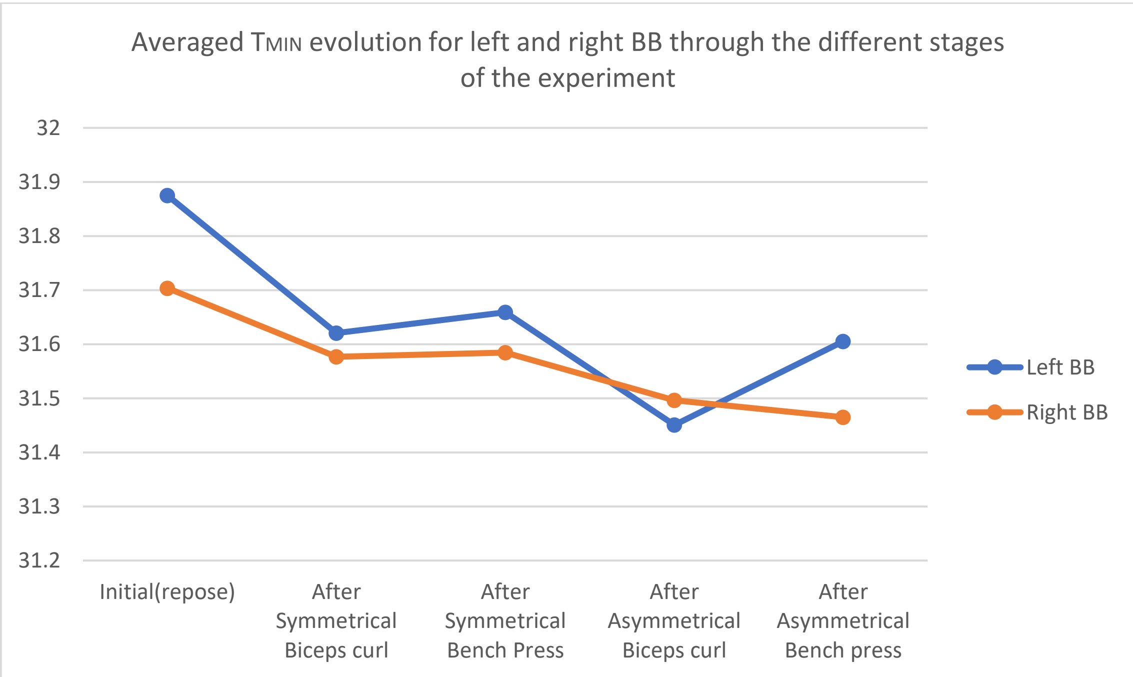

Figure 9. Chart of averaged MIN Temperature evolution for left and right BB through the different stages of the experiment

Analysing the evolution in time of this ΔT values, four variations in time can be deducted, being: ‘t1’ the difference between ΔT(repose) and ΔT(After Symmetrical Biceps Curl), ‘t2’ the difference between ΔT(After Symmetrical Biceps Curl) and ΔT(After Symmetrical Bench Press), 't3' the difference between ΔT(After Symmetrical Bench Press) and ΔT(After Asymmetrical Biceps Curl), and 't4' the difference between ΔT(After Asymmetrical Biceps Curl) and ΔT(After Asymmetrical Bench Press).

These variations were obtained subtracting the ΔT value of the earlier instant in time from the ΔT value of the later one, and they are shown in Table 6.

Table 6. Variations for ΔT_{AVG}, ΔT_{MAX}, ΔT_{MIN} for BB in time in the different time transitions of the experiment with 10% load difference.

Time transition	ΔT(time) values in BB		
	AVG	MAX	MIN
t1	0.0094	0.0056	0.1275
t2	0.0012	-0.0119	-0.0313
t3	-0.0025	0.0275	0.1206
t4	-0.0506	-0.1738	-0.1856

In Table 6. the evolution in time of the different ΔT values for BB is shown. Regarding the involvement of BB in the exercises performed, the interest is focused on the t1 and t3 values as they are the variations which involves the performing of biceps curl.

For ΔT_{AVG} these values look quite similar, both very close to 0, so no significant differences between symmetrical and asymmetrical performance of the exercise may be extracted from them.

Same results can be extracted from the results for ΔT_{MAX} and ΔT_{MIN}; however, although ΔT_{MIN}(time) in t1 and t3 is also similar, they are further from 0 than the other parameters, meaning in both cases, symmetrical and asymmetrical performing, the cold spot on the right side is hotter than in the left side.

- Results for Pectoralis Major

Table 7. Values for averaged ΔT_{AVG}, STD and ΔT_{AVG} ±STD values in the different stages of the experiment for PM in the 10% load difference experiment.

Stage of experiment	ΔT_{AVG} in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.1738	0.2633	0.4370	-0.0895
After Symmetrical Biceps Curl	0.1738	0.2515	0.4252	-0.0777
After Symmetrical Bench Press	0.1512	0.2113	0.3625	-0.0600
After Asymmetrical Biceps Curl	0.1225	0.2393	0.3618	-0.1168
After Asymmetrical Bench Press	0.1175	0.2258	0.3433	-0.1083

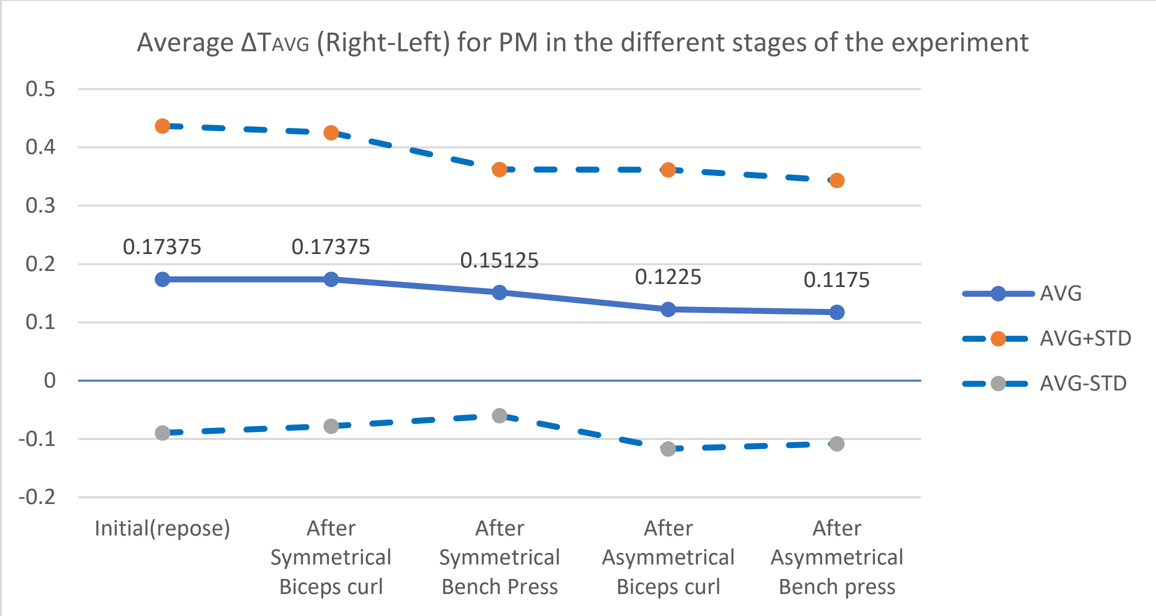

Figure 10. Chart of averaged ΔT_{AVG} values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 10% load difference experiment.

Table 7 and Figure 10 show a slightly progressive decrease in ΔT_{AVG} for Pectoralis Major once the volunteers started performing the different workouts. Still, a positive difference between right and left side muscles can be observed throughout the totality of averaged measurements, although they can turn negative as shown by the AVG±STD margin in some of the volunteers.

Table 8. Values for averaged ΔT_{MAX}, STD and ΔT_{MAX} ±STD values in the different stages of the experiment for PM in the 10% load difference experiment.

Stage of experiment	ΔT_{MAX} in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.1456	0.4728	0.6185	-0.3272
After Symmetrical Biceps Curl	0.1631	0.3581	0.5212	-0.1950
After Symmetrical Bench Press	0.1644	0.4284	0.5928	-0.2640
After Asymmetrical Biceps Curl	0.0412	0.5335	0.5748	-0.4923
After Asymmetrical Bench Press	-0.0156	0.5700	0.5544	-0.5856

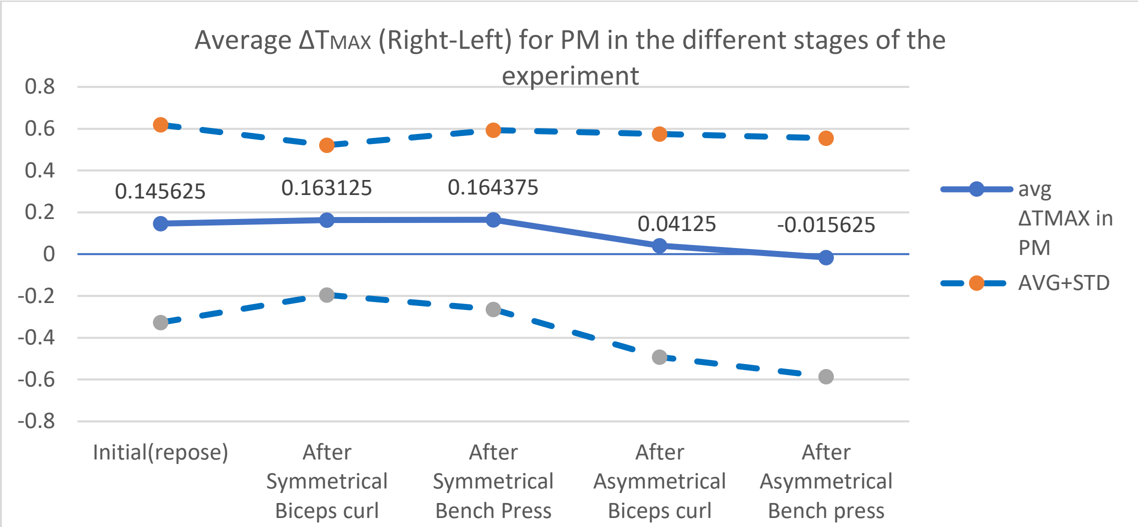

Figure 11. Chart of averaged ΔT_{MAX} values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 10% load difference experiment.

From Table 8 and Figure 11, it can be extracted that ΔT_{MAX} shows at the first three measurements, repose and both symmetrical exercises, a positive difference meaning averaged right T_{MAX} is higher at these stages than T_{MAX} on the left side. However, this difference tends to zero or even negative values once patients performed the asymmetrical exercises. In Figure 12, it can be seen how both averaged temperatures drop until slightly stabilising around a temperature of 34ºC.

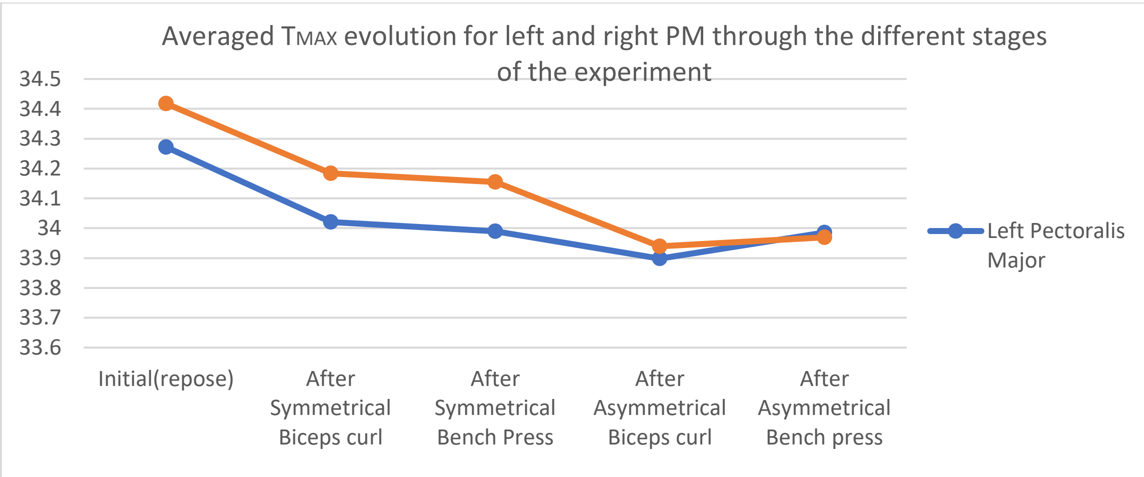

Figure 12. Chart of averaged T_{MAX} evolution for left and right PM through the different stages of the experiment

Table 9. Values for averaged ΔT_{MIN}, STD and ΔT_{MIN} ±STD values in the different stages of the experiment for PM in the 10% load difference experiment.

Stage of experiment	ΔT_{MIN} in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.2900	0.4541	0.7441	-0.1641
After Symmetrical Biceps Curl	0.1850	0.4293	0.6143	-0.2443
After Symmetrical Bench Press	0.0638	0.3661	0.4298	-0.3023
After Asymmetrical Biceps Curl	0.0375	0.3755	0.4130	-0.3380
After Asymmetrical Bench Press	0.0725	0.4163	0.4888	-0.3438

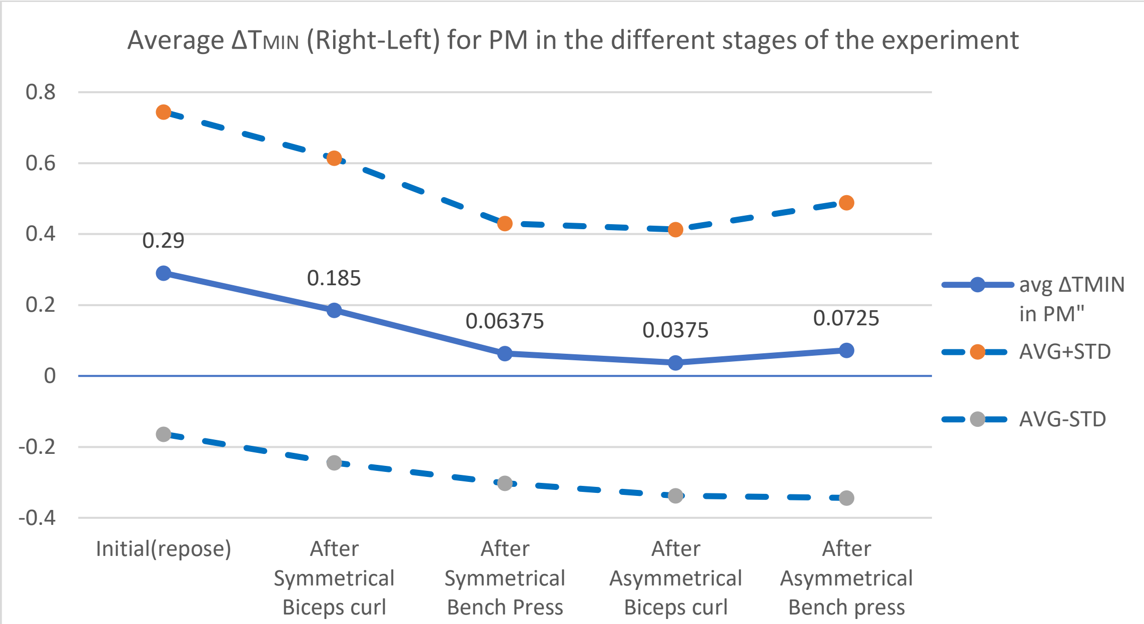

Figure 13. Chart of averaged ΔT_{MIN} values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 10% load difference experiment.

Table 9 and Figure 13 show an initial relatively high positive difference between right and left T_{MIN} and how these values tend to stabilize around zero after starting to perform the different exercises of the experiment; although the averaged ΔT_{MIN} values positiveness, their closeness to zero and their standard deviation values show again the possibility of these values to turn negative, even more in the three latest stages.

Table 10. Variations for ΔT_{AVG}, ΔT_{MAX}, ΔT_{MIN} for PM in time in the different time transitions of the experiment with 10% load difference.

Time transition	ΔT(time) values in PM		
	AVG	MAX	MIN
t1	0.0000	0.0175	-0.1050
t2	-0.0225	0.0013	-0.1213
t3	-0.0287	-0.1231	-0.0263
t4	-0.0050	-0.0569	0.0350

In Table 10 variations in time between all the stages of the experiment for the different ΔT are shown. This time, the focus is on t2 and t4 as they are the variations which involve the PM, as they are obtained when comparing the state before and after the realisation of bench press, symmetrically and asymmetrically, respectively.

As in the BB results, ΔT_{AVG} (time) do not differ in a significant way between t2 and t4, so again these results may not be useful to determine the way of performing the exercise.

Regarding ΔT_{MAX}, there is neither a significant difference between performing the workout symmetrically and asymmetrically. As for ΔT_{MIN}, a more significant difference appears, although it seems too low to really be representative.

4.2. Experiment with 20% load difference on the asymmetrical exercises.

The second way of performing the experiment was following exactly the same procedure but increasing the load difference to a 20%, i.e. in the asymmetrical exercises the lower load was for this experiment 20% lower than the load used in the symmetrical exercises. So that, same values were measured and compared between the collateral muscles studied: T_{AVG}, T_{MAX}, T_{MIN}.

- Results for Biceps Brachii

Table 11 . Values for averaged ΔT_{AVG}, STD and ΔT_{AVG} ±STD values in the different stages of the experiment for BB in the 20% load difference experiment.

Stage of experiment	ΔT_{AVG} in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	-0.0069	0.2575	0.2507	-0.2644
After Symmetrical Biceps Curl	0.0550	0.1939	0.2489	-0.1389
After Symmetrical Bench Press	-0.0156	0.2705	0.2548	-0.2861
After Asymmetrical Biceps Curl	-0.0656	0.3112	0.2456	-0.3768
After Asymmetrical Bench Press	-0.0469	0.2258	0.1789	-0.2727

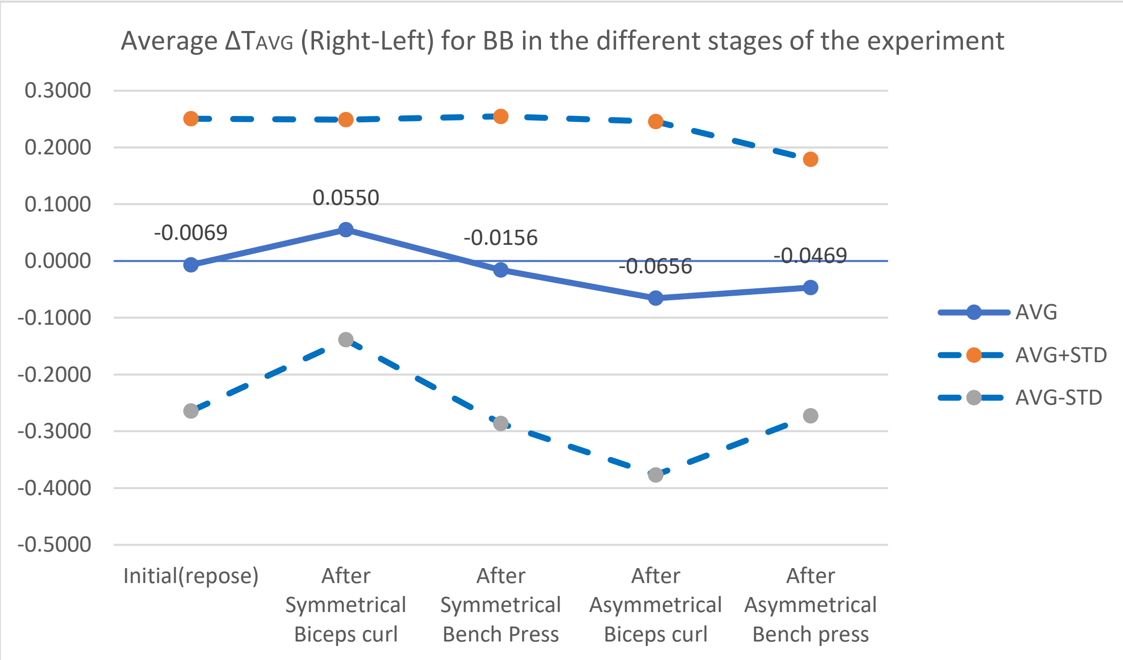

Figure 14. Chart of averaged ΔT_{AVG} values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 20% load difference experiment.

In Table 11 and Figure 14 ΔT_{AVG} values are shown and displayed, as it is observable all of them are quite close to zero; however, focusing on the stages where biceps curl was performed, a difference in values for ΔT_{AVG} can be appreciated, after the symmetrical stage this difference value turned as a positive value, while after the asymmetrical exercise it turned negative, meaning the average temperature for right Biceps Brachii was at first higher and then lower than the temperature for left side Biceps Brachii.

Table 12. Values for averaged ΔTMAX, STD and ΔTMAX ±STD values in the different stages of the experiment for BB in the 20% load difference experiment.

Stage of experiment	ΔTMAX in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.0094	0.3756	0.3850	-0.3662
After Symmetrical Biceps Curl	0.0762	0.2291	0.3054	-0.1529
After Symmetrical Bench Press	0.0681	0.4769	0.5450	-0.4087
After Asymmetrical Biceps Curl	-0.0481	0.4388	0.3907	-0.4869
After Asymmetrical Bench Press	-0.0925	0.3123	0.2198	-0.4048

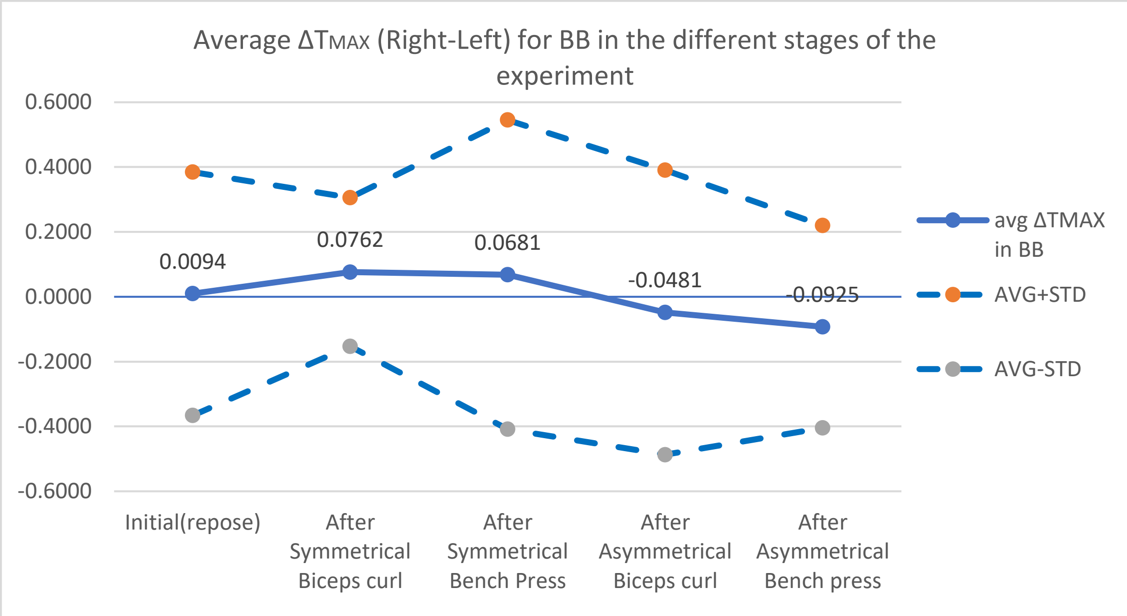

Figure 15. Chart of averaged ΔTMAX values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 20% load difference experiment.

Table 12 and Figure 15 are representations of the different ΔTMAX values for Biceps Brachii, again these difference values turn to be close to zero for all stages and can altern between positive and negative values; nevertheless, different behaviours can be observed after performing biceps curl symmetrically and asymmetrically, while in the first case a slight increase for ΔTMAX can be seen, the opposite response appeared in the second.

Table 13. Values for averaged ΔTMIN, STD and ΔTMIN ±STD values in the different stages of the experiment for BB in the 20% load difference experiment.

Stage of experiment	ΔTMIN in BB			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	-0.0106	0.5438	0.5332	-0.5544
After Symmetrical Biceps Curl	0.1400	0.3872	0.5272	-0.2472
After Symmetrical Bench Press	0.2086	0.6739	0.8824	-0.4653
After Asymmetrical Biceps Curl	-0.1163	0.4543	0.3381	-0.5706
After Asymmetrical Bench Press	0.0544	0.5899	0.6443	-0.5355

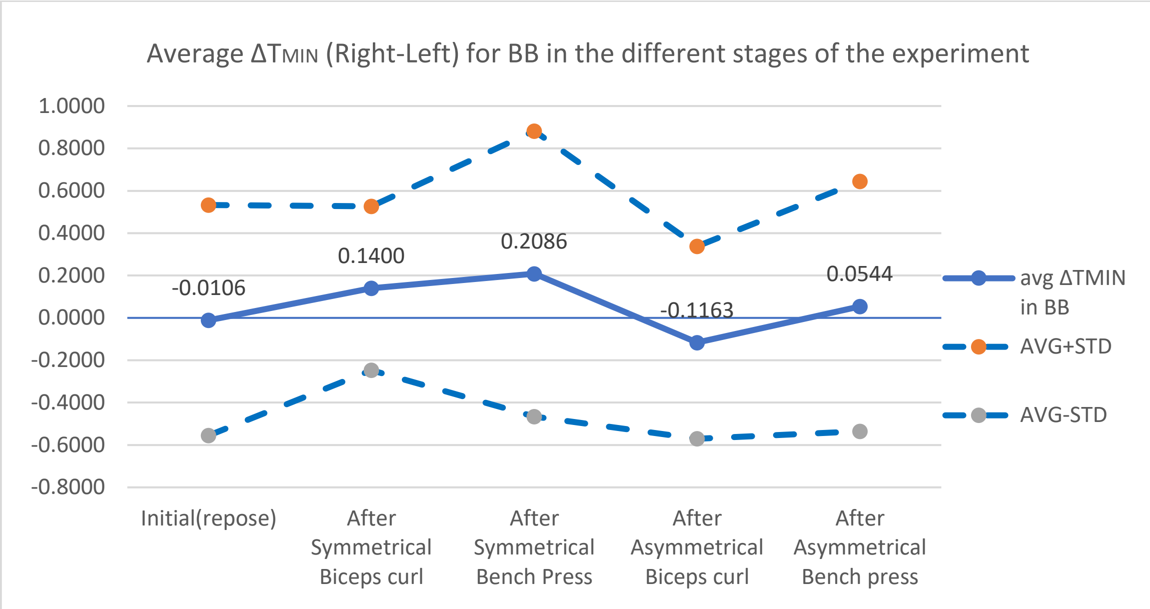

Figure 16. Chart of averaged ΔT_{MIN} values in the different stages of the experiment, alongside the AVG±STD margin for BB in the 20% load difference experiment.

Table 13 and Figure 16 show the different ΔT_{MIN} values for Biceps Brachii. It can be seen how these values showed an increment in every stage but after performing asymmetrical biceps curls where a relatively high decrease was observed.

Table 14. Variations for ΔT_{AVG}, ΔT_{MAX}, ΔT_{MIN} for BB in time in the different time transitions of the experiment with 20% load difference.

Time transition	ΔT(time) values in BB		
	AVG	MAX	MIN
t1	0.0619	0.0669	0.1506
t2	-0.0706	-0.0081	0.0686
t3	-0.0500	-0.1163	-0.3248
t4	0.0187	-0.0444	0.1706

Table 14 gives the values of the variations in time for the different ΔT values through the whole experiment. As done in the 10%load difference exercise, regarding the involvement of Biceps Brachii in the distinct steps, the focus is now on t1 and t3, as they are the variations in ΔT between before and after performing biceps curl, symmetrically and asymmetrically respectively.

It can be observed that in t1 the variation for average ΔT_{AVG} of Biceps Brachii for the group of volunteers takes a value above zero, which means right side Biceps Brachii T_{AVG} experimented a higher increase than left side Biceps Brachii after realisation of symmetrical biceps curl. This is observable on Figure 17. Whereas t3 shows a negative value in contrast, this time it was the left side muscle the one which experimented a higher variation in ΔT_{AVG} value. This could be leaded by the fact of the differences in sides' loads, higher in the left side in the asymmetrical exercise.

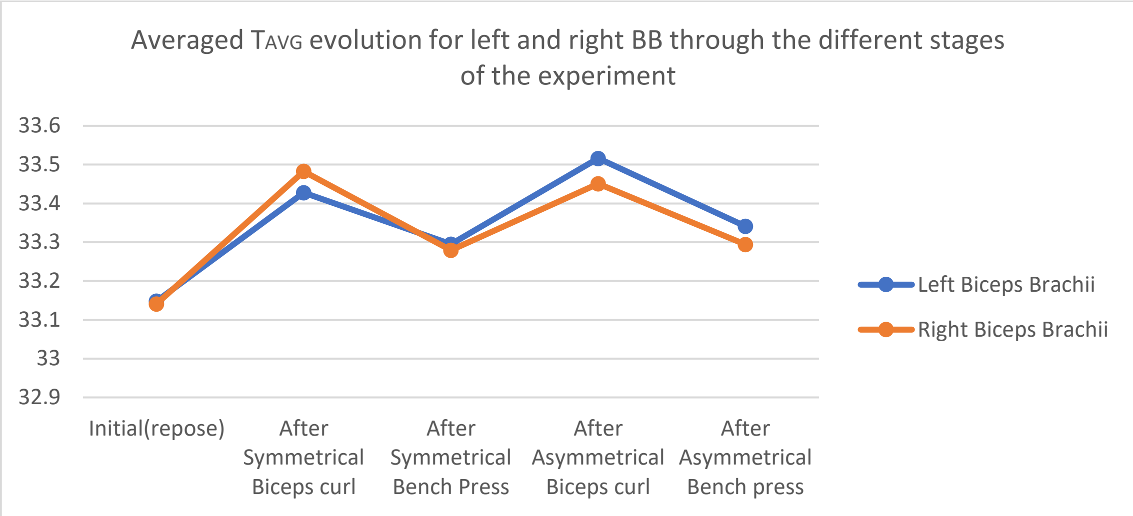

Figure 17. Chart of averaged T_{AVG} evolution for left and right BB through the different stages of the experiment

Regarding ΔT_{MAX} and ΔT_{MIN}, similar behaviour as for ΔT_{AVG} was noticed. After the realisation of symmetrical biceps curl the value for both parameters turned positive, although very close to zero. Then, after the realisation of asymmetrical biceps curl these values were negative, for both, the difference from zero was higher than the positive deviation from the 'zero line' observed after t1, being more remarkable for ΔT_{MIN}. Figure 18 shows the different measured values for left and right T_{MIN} in Biceps Brachii. It can be seen how the right-side muscle experimented almost no variation after performing biceps curl symmetrically and a slight decrease after performing the exercise asymmetrically. In contrast, left-side Biceps Brachii T_{MIN} showed a 0.14ºC decrease after the symmetrical workout and a 0.26ºC increase after the asymmetrical exercise. This changes in T_{MIN} could be due to a more regularly distributed skin temperature which would lead to a raise of the left Biceps Brachii T_{MIN} value after performing the exercise asymmetrically with a higher load than the right side.

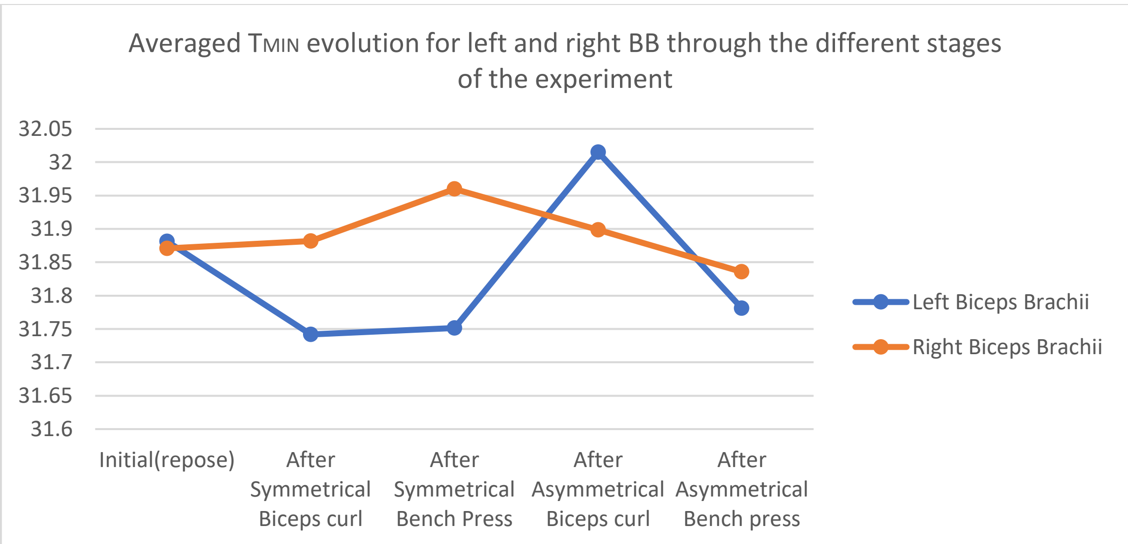

Figure 18. Chart of averaged T_{MIN} evolution for left and right BB through the different stages of the experiment

- Results for Pectoralis Major

Table 15. Values for averaged ΔTAVG, STD and ΔTAVG ±STD values in the different stages of the experiment for PM in the 20% load difference experiment.

Stage of experiment	ΔTAVG in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.0481	0.2790	0.3271	-0.2308
After Symmetrical Biceps Curl	0.0544	0.2560	0.3104	-0.2016
After Symmetrical Bench Press	0.0538	0.3259	0.3797	-0.2722
After Asymmetrical Biceps Curl	0.0525	0.3203	0.3728	-0.2678
After Asymmetrical Bench Press	0.1175	0.3142	0.4317	-0.1967

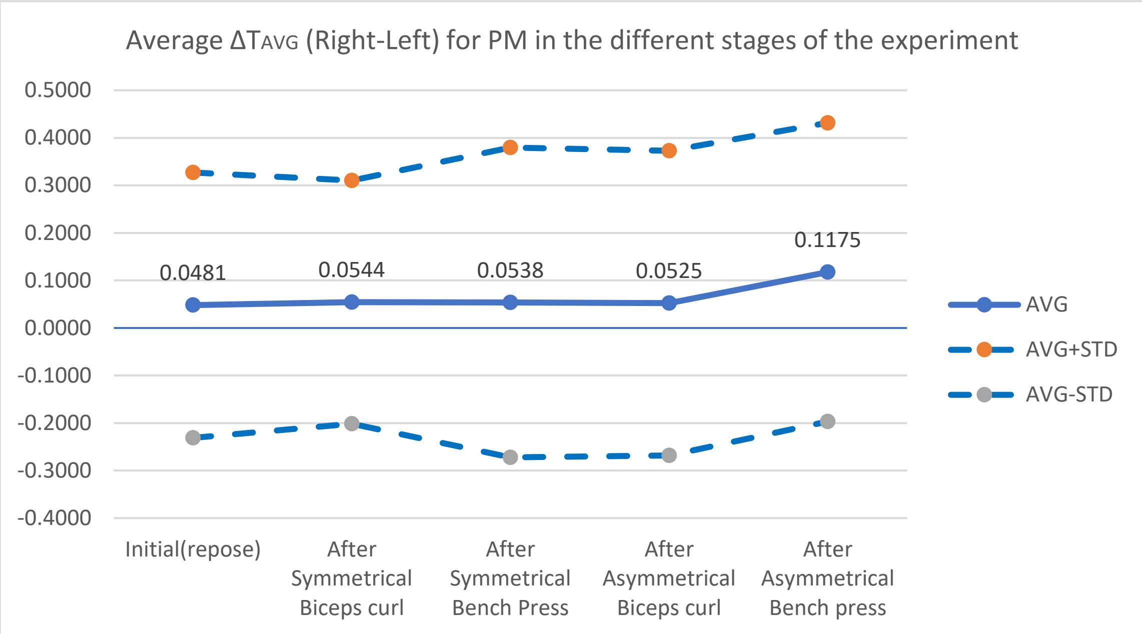

Figure 19. Chart of averaged ΔTAVG values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 20% load difference experiment.

Table 15 and Figure 19 show the values of ΔTAVG along the different stages of the experiment. As it can be observed this parameter stayed practically stabilized around 0.05ºC in all stages but the last one, after performing the asymmetrical bench press where a slight positive increase is observed.

Table 16. Values for averaged ΔTMAX, STD and ΔTMAX ±STD values in the different stages of the experiment for PM in the 20% load difference experiment.

Stage of experiment	ΔTMAX in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	0.0569	0.1917	0.2486	-0.1349
After Symmetrical Biceps Curl	0.0712	0.5240	0.5952	-0.4527
After Symmetrical Bench Press	-0.1019	0.2088	0.1070	-0.3107
After Asymmetrical Biceps Curl	-0.0975	0.2980	0.2005	-0.3955
After Asymmetrical Bench Press	0.0169	0.3815	0.3984	-0.3646

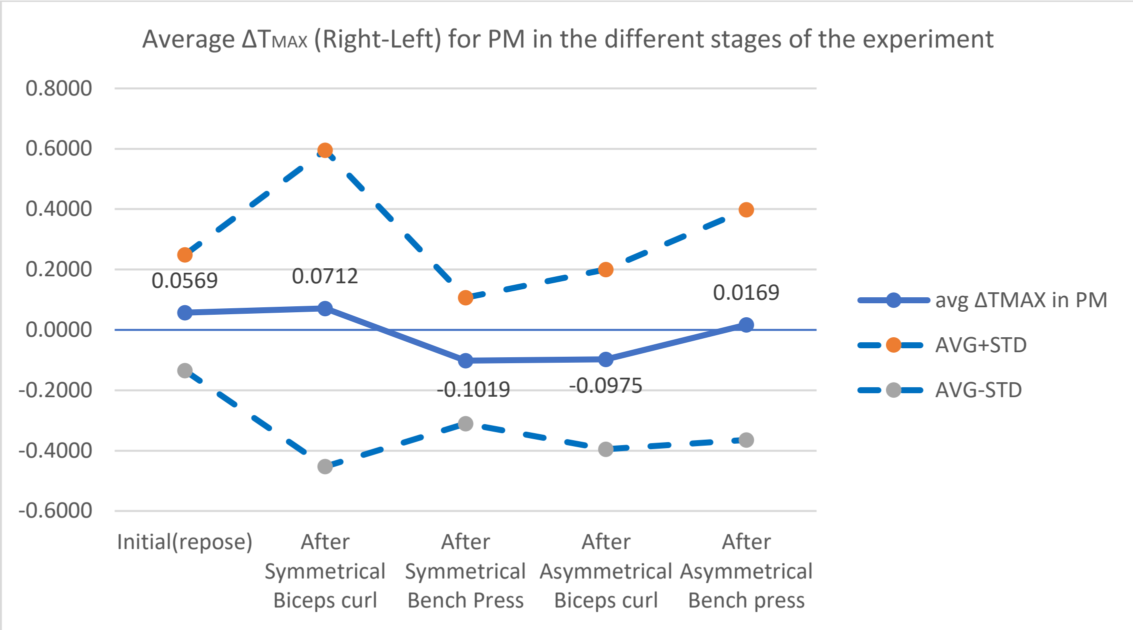

Figure 20. Chart of averaged ΔTMAX values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 20% load difference experiment.

Evolution of ΔTMAX can be observed in Table 16 and Figure 20. This average value at repose was close to zero and was the measurement with the lowest standard deviation. ΔTMAX practically didn't vary at the following stage, but in the measurement after performing symmetrical bench press this value experienced a decrease which made this difference negative. This difference is due to an increase in TMAX in the left side and a decrease on the right as shown in Figure 21. In the last two stages, similar behaviour is observed between left and right side, although the final increase in the right Biceps Brachii TMAX is higher than in the left side, which made that the last value of ΔTMAX becomes almost zero again, this higher increase on the right side after asymmetrical bench press may be leaded by the fact that the right side was the one with a higher load on it.

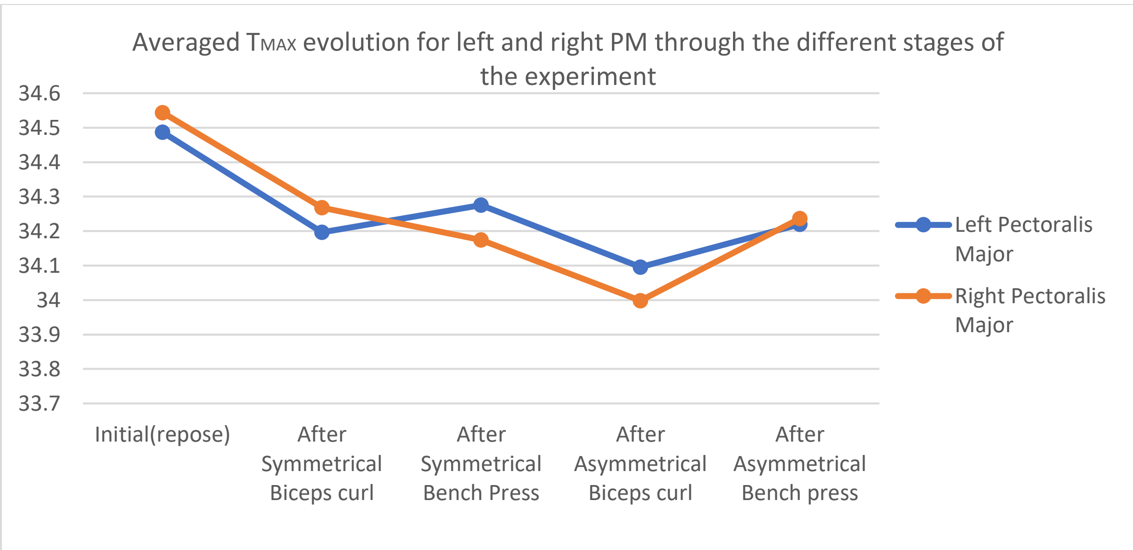

Figure 21. Chart of averaged TMAX evolution for left and right PM through the different stages of the experiment

Table 17. Values for averaged ΔTMIN, STD and ΔTMIN ±STD values in the different stages of the experiment for PM in the 20% load difference experiment.

Stage of experiment	ΔTMIN in PM			
	AVG	STD	AVG+STD	AVG-STD
Initial(repose)	-0.0456	0.4196	0.3739	-0.4652
After Symmetrical Biceps Curl	-0.0663	0.3302	0.2640	-0.3965
After Symmetrical Bench Press	-0.0544	0.3905	0.3361	-0.4449
After Asymmetrical Biceps Curl	-0.0031	0.3734	0.3703	-0.3765
After Asymmetrical Bench Press	0.0969	0.3352	0.4321	-0.2383

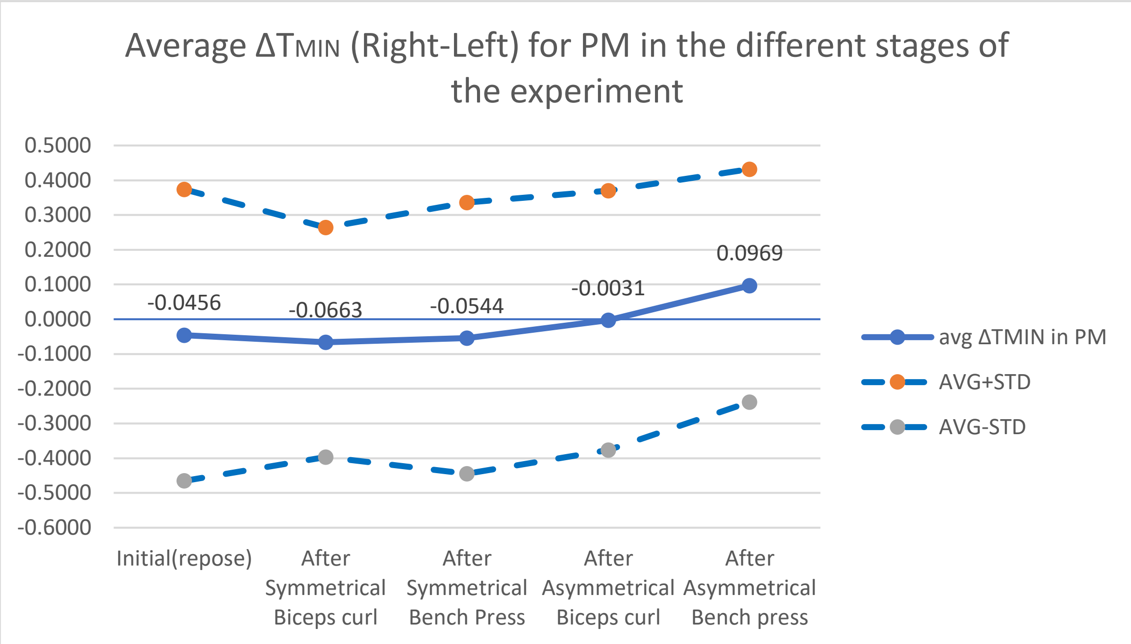

Figure 22. Chart of averaged ΔTMIN values in the different stages of the experiment, alongside the AVG±STD margin for PM in the 20% load difference experiment.

Table 17 and Figure 22 describe the different values ΔTMIN took in the different stages of the experiment. These values seem to remain stable in negative values close to zero but experiment a slight increase in the last stage, after the performing of the asymmetrical bench press, which may as well be due to the higher load on the right side.

Table 18. Variations for ΔTAVG, ΔTMAX, ΔTMIN for PM in time in the different time transitions of the experiment with 20% load difference.

Time transition	ΔT(time) values in PM		
	AVG	MAX	MIN
t1	0.0063	0.0144	-0.0206
t2	-0.0006	-0.1731	0.0119
t3	-0.0012	0.0044	0.0512
t4	0.0650	0.1144	0.1000

Table 18 is a representation of the variation in time of the three analysed ΔT parameters. As the focus is now on Pectoralis Major behaviour, the attention is paid on t2 and t4 as they involve the performing of symmetrical and asymmetrical bench press, respectively.

For ΔT_{AVG} practically no variation is observed after the symmetrical bench press is performed and a slight increase appeared after the asymmetrical exercising. Similar behaviour is observed for ΔT_{MIN}, although the increase after the asymmetrical exercising is slightly higher. Different evolution in time is perceived for ΔT_{MAX} parameter, where the practically no variation in t2 is changed for a relatively high decrease in comparison with the resting values in Table 18; nevertheless, similar increase is observed after the asymmetrical exercising as for ΔT_{AVG} and ΔT_{MIN}.

5. Discussion

As seen in theory, thermogenesis caused by physical activity is not the only factor which produces changes on skin temperature, so the results might be affected by various factor which could not be controlled in the experiment. These other variables could derive from the different thermoregulation processes for the distinct individuals, which depend on the age, body fat percentage and other metabolic and physiological processes. After the realisation of physical activity and the posterior repose time of five minutes, the thermal response may be influenced by two determinant factors, they are the sweat producing and its evaporation and the blood flow redistribution (Gomes Vieira, Sillero-Quintana, Gomes da Silva, Ottoline Marins, & Bouzas Marins, 2020). Both of them are supposed to cause a decrease on the measured value of skin temperature and might affect the results obtained in the experiment.

It is also important to mention the possible presence of errors on the manual segmentation of the region of interest or on the thermograms taking. These errors were tried to be the most reduced as possible by following a standard procedure for the capture of the various thermal images and by using same criteria when segmentation of them.

Furthermore, also of importance to be mentioned is the reduced number of individuals for each study, the presence of abnormalities in any of the studied volunteers is subjective to cause alterations in the final result as any of them has the same weight when calculating averaged parameters as it was done.

Having all of the above considered, the results analysis shows some patterns depending on the exercise performed which could lead to the goal of this thesis.

As the symmetrical part of the experiment is exactly similar for both of the groups, the differences in results between experiments should reside on the after asymmetrical exercises performing thermograms, as well as different responses from the symmetrical exercises results were expected.

This resemblant behaviour is mostly observed when analysing the average skin temperature of the regions of interest, and do not appear when analysing the minimum and maximum temperature values. These two last parameters are very susceptible to the presence of hot and cold spots that might appear due to the presence of sweating or other influential factors which cannot be accurately controlled and may appear or not on the different individuals. Considering this, these parameters may not be determinant in the assessing of the grade of symmetry when exercising.

Hence, the focus was pointed onto the average skin temperature parameters.

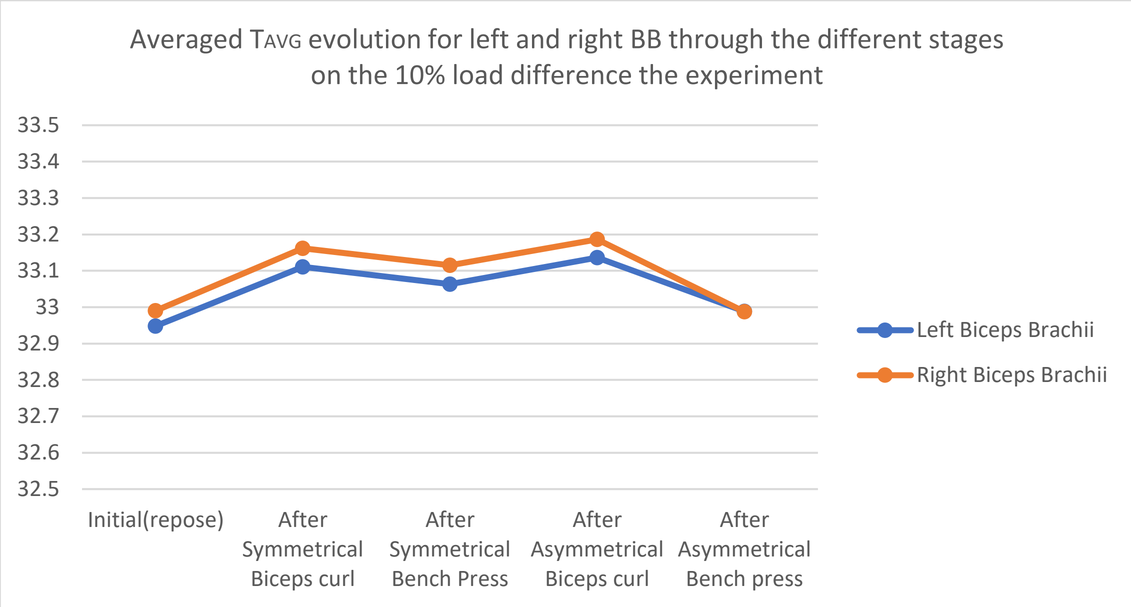

Figure 23. Chart of averaged TAVG evolution for left and right BB through the different stages on the 10% load difference the experiment.

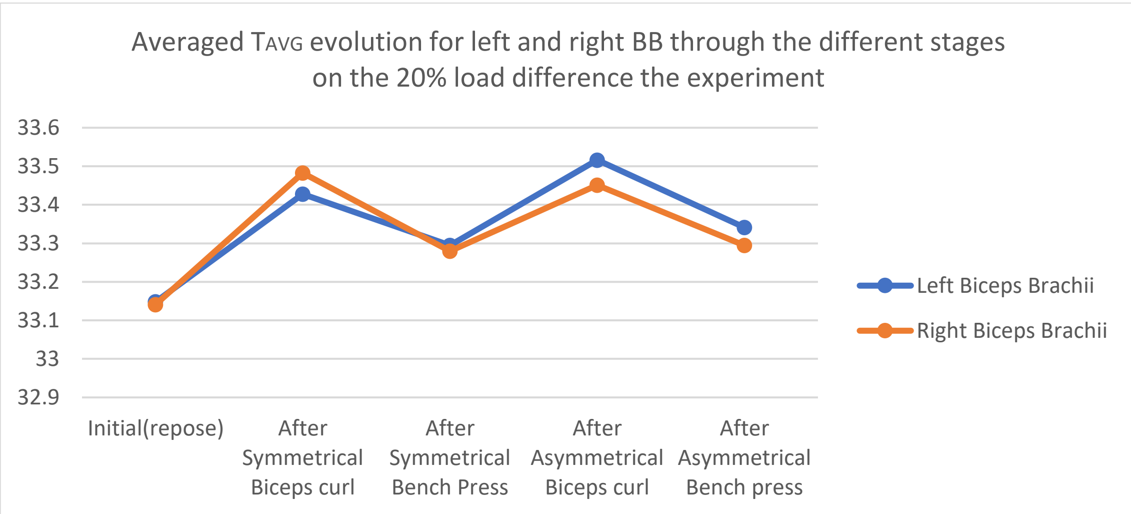

Figure 24. Chart of averaged TAVG evolution for left and right BB through the different stages on the 20% load difference the experiment.

On Figure 23 and Figure 24, it is observable that reasonable similarities in evolution of Biceps Brachii TAVG for both experiments exist. Although average values of skin temperature are slightly higher on the second group of volunteers, two groups describe a certain pattern through the first three thermograms, correspondent to the initial one and the two thermograms after performing symmetrical exercises. Analysing Biceps Brachii behaviour, the focus should lie on the variation of this TAVG parameter before and after performing biceps curl.

For both groups of volunteers, right TAVG is slightly higher than the left one after the performing of symmetrical biceps curl. Different results are obtained in the two experiments when analysing the variation an asymmetrical performing of the exercise cause. While on the 10% load difference experiment TAVG of left and right experimented practically identical variations, on the 20% load difference experiment this turns different, being the variation in left TAVG slightly higher than in the right side. This may be due to the higher load difference for the second group, so the left Biceps Brachii activity gets to be of higher intensity, and this is expressed in form of higher skin temperature.

Table 19. Variations of BB ΔTAVG in time in the different time transitions of the experiment with 10% and 20% load difference.

Time transition	ΔTAVG(time) values in BB	
	10 % load difference	20% load difference
t1	0.0094	0.0619
t2	0.0012	-0.0706
t3	-0.0025	-0.0494
t4	-0.0506	0.0181

Table 19 shows the variation through the different stages for the Biceps Brachii ΔTAVG, for both 10% and 20% load difference experiment. As done in the results section, in Table 19 it is again used the ‘t’ terms to refer to the transitions between and after each performed exercise.

Focusing on t1 and t3 as they involve the transition between before and after performing biceps curl, some unwanted differences appear in t1 as both values are supposed to be equal, this difference, though small is relatively high in comparison with the other values obtained. In t3 the difference observed is expected, as the higher loaded side was the left one, still, this variation is quite small, considering that the right side was 20% less loaded than the left one.

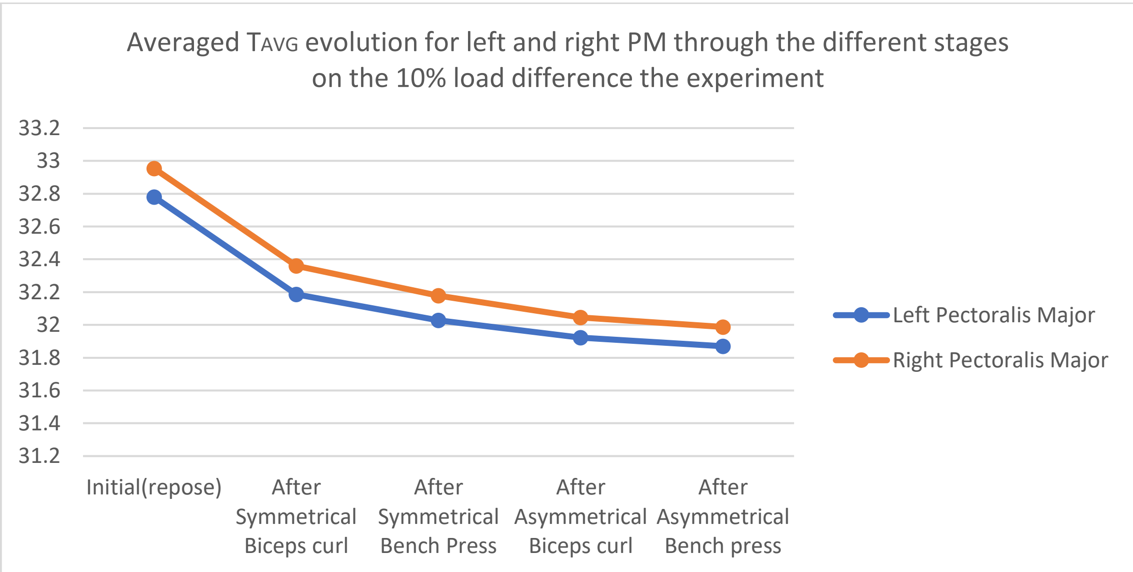

Figure 25. Chart of averaged TAVG evolution for left and right PM through the different stages on the 10% load difference the experiment.

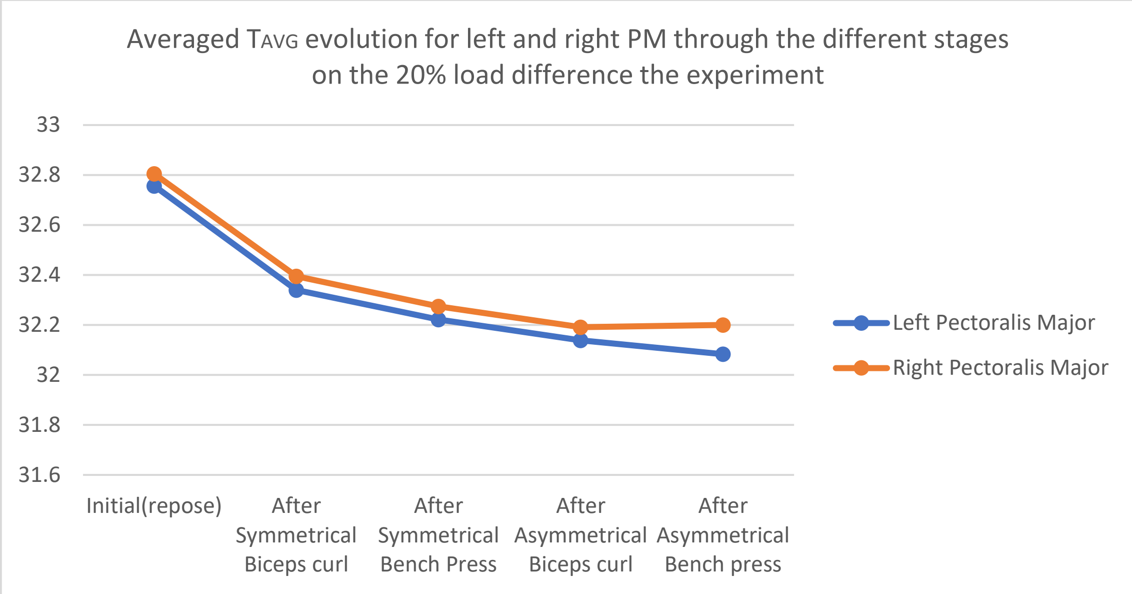

Figure 26. Chart of averaged T_{AVG} evolution for left and right PM through the different stages on the 20% load difference the experiment.

Figure 25 and Figure 26 show the results obtained during the experiment for left and right T_{AVG} in Pectoralis Major. Although the ΔT_{AVG} values are higher in the first group, very similar behaviour is observed for the first three thermograms and a slight difference is detectable in the variation after performing asymmetrical bench press, the generalized decrease on temperature could be due to the sweating contribution to the skin temperature value.

In the 20% load difference experiment, a slightly higher ΔT_{AVG} value for this last stage in comparison with the other stages values was observed, while this was not observed in the 10% load difference experiment where these variances between stages remained practically constant around zero for every stage. Table 20 show the variations of Pectoralis Major ΔT_{AVG} between all the steps of the experiment, for both of the 2 groups studied.

Table 20. Variations of PM ΔT_{AVG} in time in the different time transitions of the experiment with 10% and 20% load difference.

Time transition	ΔT_{AVG}(time) values in PM	
	10 % load difference	20% load difference
t1	0.0000	0.0063
t2	-0.0225	-0.0006
t3	-0.0287	-0.0012
t4	-0.0050	0.0650

This variation in t4 for the 20% load difference experiment, although it is relatively small, is the highest observed one, moreover it is positive which might be leaded by the fact that the right side was the higher loaded when bench pressing.

Although these differences are observed for both Biceps Brachii and Pectoralis Major and could lead to the determination of if the exercise is being performed symmetrically or asymmetrically, the use of the averaged values and the relatively high standard deviation of them don't ensure this pattern is necessarily going to be present on every volunteer of the study or in further volunteers analysed with the same methodological procedure. Furthermore, as seen in Table 19 and Table 20 these values may be too low for being determinant, as similar variations in absolute values could be observed when they were not expected as in Biceps Brachii on the 20% load difference experiment, on the symmetrical exercising.

6. Conclusions

Thermogenesis due to physical activity is expected to cause an increase on the skin temperature and this increase is expected to be directly dependent to the intensity of the exercise. Symmetrical exercising is supposed to been expressed as similar intensity on collateral muscles which may derive into similar variation of skin temperature on both sides.

However, this thermogenesis is not the only factor which affects the measurement and its effect on the total grade of variation of skin temperature could be masked by them. Furthermore, collateral muscles may not be equally excited by equal physical activity intensity due to different development of collateral muscles, presence of injuries or a bad technique while performing the exercises.

In order to prove if determining in which way an exercise is made was possible, an experiment procedure was created. On it, different individuals performed symmetrical and asymmetrical gym exercises: dumbbell biceps curl and dumbbell bench press. Two groups of volunteers were studied, with variations in the percentage of load difference between collateral sides in the asymmetrical part.

Thermography was used to measure the skin temperature on the different stages of the experiment as this technique enables the measurement of surfaces temperature in a quick and non-invasive way.

After the realisation of the experiment and the posterior analysis of the results, non-determinant conclusions could be extracted, although better results were obtained when the load difference was higher.

Probably, the reduced number of volunteers for the study was a determinant factor for its non-decisive outcome. Further experiments should be performed in a larger number of individuals to prove if this factor was really determinant or if the method proposed is not adequate.

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