[213011] Design of an application based on machine learning-computer vision techniques for the physiological workload assessment in dynamics manual task

Valentina Cubillos Cifuentes[a,c] , Cristhian Felipe Quesada Martinez[a,c] , Valentina Rosero Pauwels[a,c], Paula Alejandra Vergara Rubio[a,c] ,

Luis Andrés Saavedra Robinson[b,c]

[an] *Industrial engineering student*
[b] *Professor, Director of the degree project, Department of Industrial Engineering*
[c] *Pontificia Universidad Javeriana, Bogotá, Colombia*

Abstract

Nowadays, ergonomics has been assuming a very important role within organizations, as they impose higher demands on employees to remain competitive in the market. This discipline emphasizes the care of the people who work in organizations, providing employees with a more productive development environment and reducing the risk of obtaining musculoskeletal disorders in employees who perform dynamic manual activities such as lifting and carrying loads.

This degree project develops improvements in the ergonomic evaluation method of direct observation, through the modification of algorithms where a non-invasive application was developed that allows computer vision, to obtain and measure physiological parameters such as heart rate to perform an ergonomic evaluation under the criteria of Frimat. The evaluation offered by the application will drastically reduce the subjectivity of the evaluation of the professional and will support the technological transformation integrated with Industry 4.0, giving the possibility that any type of company can make use of this type of technology without drastically increasing its costs.

This degree project was developed mainly under the Design Thinking methodology, developing within this, other methodologies or tools such as the empathy map, the five hats, and SCRUM where the collection of current data and the analysis of the center was initially performed, ending in the complete design of the application and its proper functioning. The application complies with the measurement of the heart rate of the subject while performing dynamic load tasks and in turn with the measurement of the ergonomic risk presented.

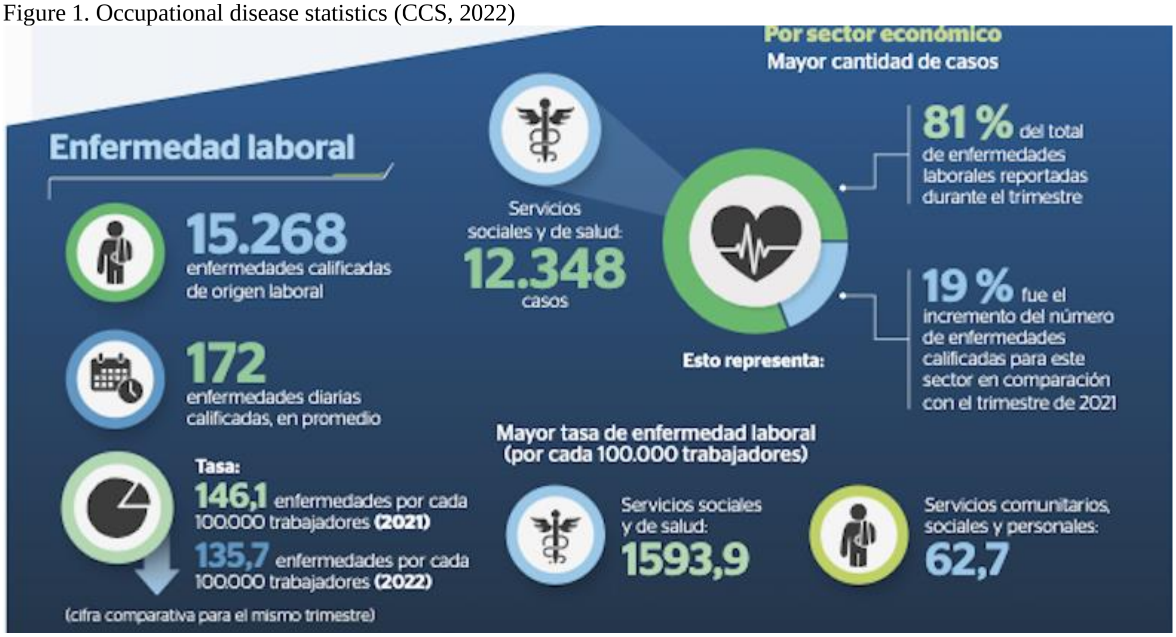
The data reported by the application were supported, on the one hand, by performing a statistical analysis through a repeated-measures ANOVA where a favorable result was obtained showing that the combination Height-Repetitions is the one that presents the greatest effect on the response variable (HR). On the other hand, the validation of its functioning with a pulsometer was carried out with a paired statistical T-test, concluding that the application has a 97.5% efficiency concerning the direct measurement equipment.

Keywords: Ergonomics, heart rate, face detection, computer vision, work-physiology, machine learning, application

1. Justification and problem statement

Work-related musculoskeletal disorders (MSDs) are disorders of body structures such as muscles, joints, tendons, ligaments, nerves, bones, and the circulatory system, caused or aggravated mainly by work and the effects of the work environment. One of the physical factors causing MSDs is the application of forces, such as lifting, carrying, pulling, pushing, and the use of tools used in manual labor.(Instituto Canario de Seguridad Laboral, n.d.)

Figure 1. Occupational disease statistics (CCS, 2022)



Source: (CCS, 2022)

In Colombia, according to the most recent report for the year 2022 generated by the General System of Occupational Risks of the Ministry of Health, it was evidenced that occupational diseases between January and March, 15,268 cases were reported (See Figure 1) with an average of 172 events per day. In addition, it is mentioned that the sector that presented the highest rate of illnesses was "Social Services and Health", with 1,593 cases per 100,000 workers, which represents 81% of the total reported during the quarter. (CCS, 2022)

Employees suffering from some type of occupational disease in the country are covered by Law 1562 of 2012, which establishes the provisions on occupational health and occupational hazards, for applicability to all Colombian companies, includingSmall and Medium Enterprises (SMEs). The latter constitute the highest percentage of industrial organizations in many parts of the world, especially in developing countries, as in Latin America where the figure is over 90% (Piraquive, 2018) making up one of the most important productive forces in the region. However, SMEs must deal with some difficulties such as limited resource management, low managerial skills, low market penetration, and communication problems, (Krause & Schutte, 2015) and in addition, they rarely pay attention to having infrastructure or facilities that guarantee comfort and ergonomics for their employees. This implies that the results of the organizations are directly affected by the MSDs suffered by the employees, due to the accumulation of lost work hours, the non-fulfillment of objectives, the congestion of workload without evacuation, and the costs due to incapacities that both the employer and the employee must assume, the hiring of a qualified person to replace the vacancy or the work overload on their coworkers, all of which generate a negative impact on labor productivity.

Therefore, it is important to analyze what ergonomics is and what it contributes to ensuring that workers do not have any type of risk and perform their activities efficiently. Organizations must ensure a high quality of working life and an optimal system of human tasks, in which an optimal balance can be maintained between the worker and the working conditions, promoting health and well-being, reducing accidents, and improving the productivity of companies.

Traditionally, many methods and tools have been developed to evaluate postures and activities related to the assigned work environment. These are classified as follows: First, self-assessment, in which each worker is given a form and evaluates himself. Secondly, human observation, which is based on time-limited observation of the workplace and collects information on angles and movements, can be seen live or viewed from a video. Thirdly, direct measurement, where anthropometric devices are used that must be placed on the worker's body, and from them, data is collected for analysis. In addition, it is important to point out that direct measurement or instrument-based methods use sensors connected to the subject to measure certain variables and provide accurate data, but they are invasive and require highly trained technical personnel to guarantee effective operation (David et al., 2008), however, the legislative frameworks in place in many countries do not ensure that this condition is met. For example, legislation in different European and American countries does not require companies to ensure that those responsible for performing these types of assessments have specific training or qualifications, therefore, in many cases, professionals do not have the recommended training to use ergonomic analysis tools or to correctly interpret the results obtained from their use (Diego-Mas et al., 2015).

Consequently, methods such as direct observation are preferred, which, although they are considered easier, do not yield accurate results, provide rather extensive results, and require a lot of time and intensive work, which translates into higher costs for the organization. Based on this there has been a growing interest in improving those techniques and tools that help the practitioner make real-time decisions without using invasive or subjective methods because the above-mentioned work measurement techniques are still based on stopwatch measurements and manual video analysis, which makes them prohibitively slow (Bauters et al., 2018).

In brief, it has been demonstrated from this review the importance of using resources that allow real-time data collection (real-time is considered the collection or processing of data in cycles of approximately one minute) of results that can be easily interpreted and that can be used specifically to improve a workplace and reduce downtime caused by staff absenteeism.

In recent years, interest has emerged in wearable devices equipped with sensors capable of measuring parameters related to postures, forces, muscle activities, and heart rate. The reason for this is that manual activities such as lifting, receiving, and transporting loads are still present in production systems, involving physical effort that requires energy consumption.

Currently, there are several evaluation methods such as spirometry, electromyography, FRIMAT coefficient, Chamoux coefficient, and energy expenditure tables that specifically focus on and measure metabolic expenditure through different variables such as heart rate, and muscle fatigue, airflow, and others. These methods have a theoretical depth in **Appendix 01** and their understanding served to identify which variables can be economically measurable and what advantages or disadvantages bring their measurement through the opinion of ergonomics professionals, who qualify these models based on criteria such as adaptability to SMEs, low implementation costs, ease of interpretation of results, and several instruments used in the current measurement and how invasive they are for the evaluated collaborator.

This made us find that the measurement model that adjusted to the requirements of the experiment and could be correctly adapted to the technological intervention was the FRIMAT coefficient. It is one of the most widely used ergonomic evaluation methods to assess the physiological demand of the workstations since it is an evaluation criterion that allows measuring the level of effort using HR monitors in short work phases. This method evaluates five cardiac criteria (FCM, ΔFC, FCMax, CCA, CCR) where each of them is assigned a coercive coefficient (from 1 to 6), then the coefficients are added together to obtain a score and thus be able to evaluate the task according to the FRIMAT evaluation table. Many researchers have utilized the Heart Rate Reserve (%HRR) as a parameter, and it has been shown that when a worker performs high levels of physical activity at work, it can have negative effects on their health, such as cardiovascular disorders (Saavedra et al., 2021). Therefore, we consider that with this method, we can have an appropriate and significant relationship with the understanding of the risk to which a collaborator may be exposed with the heart rate parameter.

Based on the information mentioned above and understanding that SMEs and companies have always been in a constant search to reduce costs and time through the use of different methods that improve the physical ergonomics of their collaborators, one of the adaptations that have been implemented in the industry to replace manual observation methods is artificial intelligence or virtual representation of processes through artificial vision, as Massiris and colleagues foresee in their article (Massiris et al., 2020).

Industry 4.0 introduces information technologies in the industry to implement a digital transformation that makes them smart. Using cyber-physical systems, the Internet of Things (IoT), Cloud Computing, and Big Data, it is possible to extract and store a large amount of data. Nevertheless, the application of Machine Learning algorithms is required to create models that give value to that data and facilitate decision-making. Due to increasing computational power and cheaper hardware, Machine Learning related research and applications in industry are becoming more numerous and challenging. Regarding this type of technology, the non-intrusive nature of vision technology, and detection, is one of the main assets of the system. Since the system does not interfere with the operator, it can generate unbiased data and information over an extended period, unlike the manual analysis tools currently in use (Bauters et al., 2018).

In the case study presented in this degree work, considering that according to a study executed by the firm Techaisle, 100% of the SMEs in the country have at least one computer with more than four years of use, we propose to integrate face detection algorithms, exposed as part of the literary background, based on machine learning together with the adaptation of heart rate acquisition.

One of the BSD-licensed machine vision and machine learning libraries has more than 2500 optimized algorithms for object detection and tracking, 3D model extraction, and stereo vision, boosting, neural networks, among others, which can be used for free in both academic and commercial applications. For object detection, algorithms based on CNN and Haar Cascade stand out (Parra, 2015). For CNN, we find one of the most commercialized ones called Mobile Net, which uses depth separable convolutions. It significantly reduces the number of parameters compared to the network with regular convolutions with the same depth in the networks. This results in lightweight deep neural networks. (Sivakumar et al., 2021).

Furthermore, the Viola-Jones algorithm, based on Haar Cascade, is an object detection method that stands out for its low computational cost, which allows it to be used in real-time. Its development was motivated by the problem of face detection, where it is still widely used, but it can be applied to other classes of objects that, like faces, are characterized by typical illumination patterns.

The algorithm is based on a series of weak classifiers called Haar-like features that can be efficiently computed from an integral image. These classifiers, which by themselves have a hit probability only slightly higher than chance, are clustered in a cascade using an AdaBoost-based learning algorithm to achieve high detection performance as well as high discriminative ability in the early stages. (Parra, 2015). The selection of the algorithm was based on the understanding of the user's needs and the limitations that could be encountered in the case study since the evaluation of their performance is linked to the design requirements. The decision criteria were Capture speed with hardware limitations, front face recognition, implementation costs, and adapted code to measure FC. These will be discussed extensively in the results of objective 1.

Considering the entry of new technologies to measure the physical conditions of workers at their workstations, because the muscular fatigue of an individual is expressed when the physical workload exceeds the worker's capacity causing fatigue and discomfort, resulting in decreased productivity and increased production costs, ¿Is it possible to integrate machine learning based on algorithms to measure the physiological load of the human being in physical activities in the workplace?

2. Background

Nowadays, within companies or organizations, a series of organized and related elements that make up the productive system is required, involving factors such as people, tools, technology, and other resources that facilitate the achievement of the main objectives of the company, always searching for the greatest integration of activities and information.

Regarding the sources mentioned above, one of the most valuable resources of a company is its human capital, this has a determining factor in the development of the organization and, to maintain a level of productivity without generating fatigue in the worker, it is necessary the mandatory study of the care of people in the work environment. To understand more about ergonomics and its connection with the advancement of technology and Industry 4.0, several studies were found presented in Table 1 that features current research on the topic of interest in different ways.

Table 1. Papers and Keywords

	KEY WORDS												
	Physical Ergonomics						Productivity	Computer Visualization				Digital twin	Machine Learning
PAPERS	WRMSD	Heart rate	Transport	Lifting	Repetitive movement	Biomechanical/ physical workload		Industry 4.0	Face detection	Motion tracking	Programming		
Saavedra et al.,(2021)	x	x		x	x								
SivaKumar et al.,(2021)								x	x		x		x
Guo et al., (2020)								x	x		x		x
Massiris et al.,(2020)	x					x	x	x	x	x	x		
Gonzalez et al.,(2019)									x		x	x	x
Bauters et al.,(2018)								x		x	x	x	
Li et al.,(2018)											x		x
Piraquive. (2018)	x		x	x		x	x						
Garcia.,(2017)		x							x	x	x		x
Greene et al.,(2017)	x		x	x	x		x			x			
Bevan et al.,(2015)	x				x		x						
Parra.,(2015)								x	x		x		x
Ballesteros.,(2014)		x					x	x	x		x		x
Csail et al., (2014)								x	x		x		x
Instituto Canario de Seguridad Laboral	x		x	x	x	x	x						

Source: Own Elaboration

Most of the current ergonomics literature pays special attention to ergonomic interventions and how they are focused on detecting and assessing the imbalance between workplace requirements and workers' physical capabilities to prevent work-related musculoskeletal disorders (WRMSD) (Massiris et al., 2020), as these are nowadays the leading cause of sick leave, work-related disabilities, and an overall loss of productivity in developed countries (Bevan, 2015)

The relationship that occurs between health and work can become positive or negative depending on the conditions and environment in which it develops. When it comes to optimal working conditions, these have an impact on proper occupational health, which in turn will trigger high performance and quality at work. If, on the other hand, the relationship is negative, either because of the high levels of demand in which man performs and the constant physical, psychological, ergonomic, or biological exposures, it leads to inadequate conditions and can trigger both physical and psychological disorders, accidents and even death (Collado Luis, 2008)

According to the Colombian Ministry of Social Protection (2004), there are 160 million new cases of occupational diseases worldwide each year, including physical and mental illnesses. It is estimated that only between 1% and 4% correspond to Latin America. According to data reported by the Ministry of Labor, in 2014 a total of 540 people died in Colombia due to occupational accidents, in 2013 755 workers died from this cause and during 2012 this figure stood at 528 cases, being lower in 2011 when it was established at 375 workers (Sánchez & Solano, 2017).

Considering the evidence, the quality of work-life is demanded in all senses, the discipline delves into different forms and methodologies that if applied together provide welfare and safety to the human being without affecting the productivity of companies.

Given what has been mentioned so far, it can be stated that to ergonomic risk situation and generate a correct design of the workplace, there are different methods to evaluate the postural load or load handling for work tasks. Also, nowadays, with modernization, automation, and adaptation to recent technologies, the use of automated methodologies is leading the way, considering the relationship between ergonomics and production.

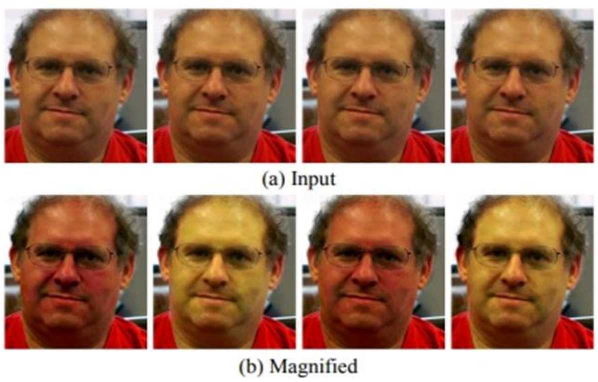
Any job that involves carrying and lifting loads generally leads to musculoskeletal disorders. Having too much or too little work can affect both the company and the individual, so the workload is key to determining the degree of ergonomics, appropriate duration, and repetitions of a particular job. One of the ways to measure the impact of ergonomics and the workload associated with a dynamic task is by measuring energy consumption, and energy metabolism, which can be done through oxygen consumption or heart rate-dependent energy consumption.

Currently, there are different ways in which the heart rate indicator can be obtained, however, the clearest and most technological advance is remote photoplethysmography, which consists of measuring vital signs by processing images obtained with a camera. The technique consists of taking a sequence of images over a region of interest (ROI) and processing these images so that each image is transformed into a data signal (Ballesteros, 2014).

This data signal analyzes the color change in the face produced by the pumping of blood or the movement of blood flow to the head. This is a method that analyzes the color changes caused in the skin, generally of the face, by blood circulation, since, during systole, the skin has a reddish tone compared to diastole, so the skin reaches a more yellowish tone (García Ruiz et al., 2017).

It has been shown from the review that according to MIT CSAIL and Quanta Research Cambridge, INC(Wu et al., 2012) reveal in their Eulerian Video Magnification method that temporal variations in videos are difficult or impossible to be seen with the human eye and displayed indicatively. The method applied in this experiment takes a standard video sequence as input and applies spatial decomposition, (See figure 2), a pixel decomposition using a Gaussian pyramid, followed by temporal filtering to the frames. The resulting signal is amplified to reveal the hidden information. With this method, it is possible to visualize the flow of blood as it fills the face and to amplify and reveal small movements.

Figure 2. An example of using our Eulerian Video Magnification framework for visualizing the human pulse. (a) Four frames from the original video sequence (face). (b) The same four frames with the subject's pulse signal amplifier(Wu et al., 2012)



Source: (Wu et al., 2012).

For these methods, the main input of information is provided by images or video sequences that can be obtained through new computer vision methods, which can detect the worker's face for occupational ergonomics applications. The literature delves into algorithms based on an artificial vision for face detection that can identify characteristics that humans cannot capture with the naked eye.

According to González and Velázquez (Gonzales & Velásquez, 2019) one of the most optimally developed algorithms is the Viola-Jones algorithm, which is based on the comparison between the light intensities of rectangular regions of images called Haar Type features, which consider adjacent rectangular regions at a specific location in a detection mask, sum the pixel intensities in each region and calculate the difference between these sums. This difference is used to categorize subsections of an image, which is calculated using an integral image.

Let us now consider different options such as the algorithm for face detection with great acceptability in the literature provided in the recent Machine Learning package, specifically Deep Learning, which is considered a subcategory of this, known as Tensor Flow Lite created by Google, called MobileNet SSD.

It is anticipated that these new tools will have a profound impact on the future of occupational ergonomics and will provide a variety of new tools and techniques for design, analysis, and evaluation in ergonomics practice (Greene et al., 2017). Based on the examples presented and following this technological lead, to maintain flexibility and maximize process efficiency, workers must be supported by automated systems that provide them with feedback on the process and signal opportunities to improve efficiency and profitability. (Bauters et al., 2018).

These algorithms may not be successful when tracking multiple objects, so experiments in different scenarios are needed to make use of them. Finally, the impact of automated data collection and analysis is shaping a new set of data-driven applications where technological advances in hardware sensors and machine learning are opening new avenues for ergonomics (Massiriset al., 2020).

3. Objectives

To design an application based on machine learning and computer vision to obtain physical load assessment and a predictive physical risk assessment of a dynamic manual workstation.

- To establish from the literature review algorithms based on machine learning and computer vision that can be integrated into an ergonomic evaluation method for biomechanical physical load assessment.
- To build the application based on the integration of existing algorithms to allow an assessment of the physiological load of the individual.
- To develop a case study to evaluate the functionality of the application.
- To compare the application with direct reading equipment to look at its effectiveness and efficiency

4. Document structure

4.1. Design Statement

The design process focuses mainly on the idea of restructuring an existing application capable of measuring heart rate by adding a list of improvements and functionalities defined under the guidelines of the project objectives, resulting in a new design of an application capable of providing an ergonomic assessment to workers performing dynamic load tasks. The redesign and development of the application consist of implementing the needs of the end user, the objectives, and the ideas that arise using the most suitable technologies for it.

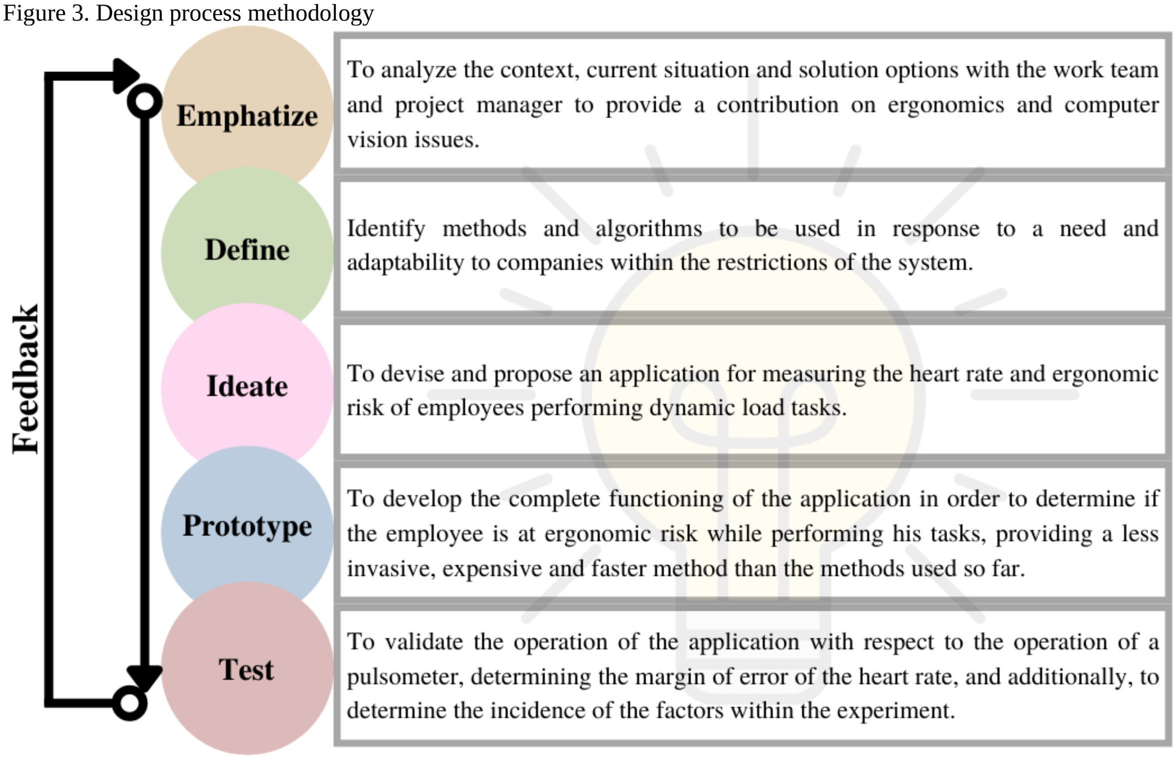
This project performs a direct measurement of Heart Rate in people who perform dynamic load tasks proposing an application to recognize the initial parameters (images), collect data, and calculate the ergonomic risk by applying the FRIMAT criteria. This application, which runs on different operating systems, reflects on the screen the heart rate of the individual and the ergonomic risk score in which it is located along with the meaning of this score, using the integration of USB cameras.

The purpose of the application is to contribute to small and medium companies with a non-invasive method, with a precision close to a pulsometer and low cost for the control of the ergonomic risk of their employees. The result of the application presents throughout a determined period the heart rate of the individual, the FRIMAT score, and the ergonomic risk in which it is found.

4.2. Design process

The development of this degree project involved 5 fundamental phases of the Design Thinking methodology explained in the image below (See Figure 3), and an additional feedback phase that refers to the recommendations received, and suggestions given for future studies.

Figure 3. Design process methodology



Source: Own Elaboration

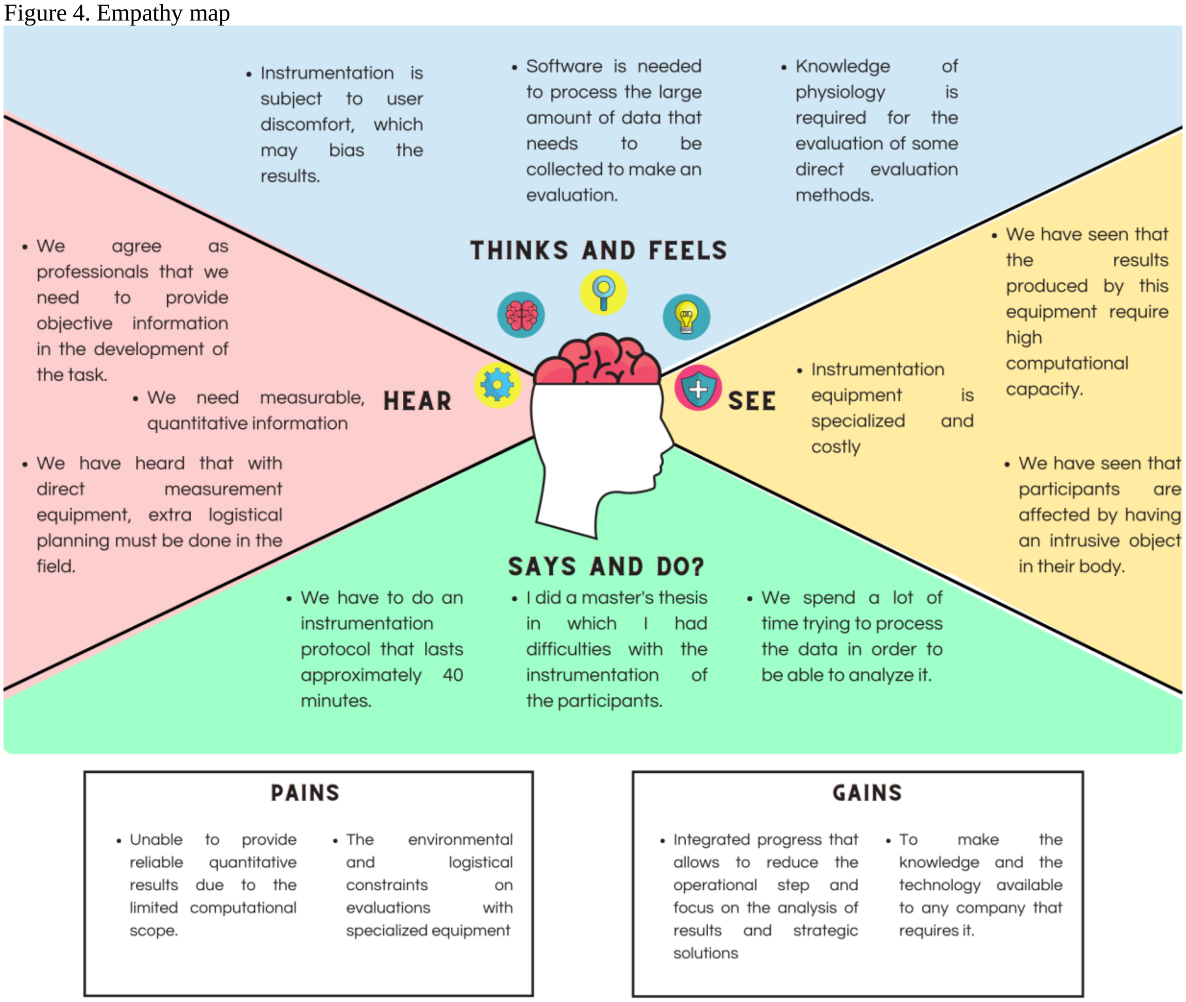
4.2.1 Emphatize

In this section the working group approached the end-user (ergonomics professionals), to identify the real needs around physiological ergonomics, getting involved specifically in the opportunities that exist in the evaluation techniques that currently exist from different perspectives. The idea was to understand the environment and interact with the actors involved by employing an in-depth interview, which was chosen due to the level of emphasis that can be reached with the questions; this was transcribed and can be found in **Appendix 01.**

In principle, this in-depth interview was intended to identify which ergonomic evaluation methods, oriented to the evaluation of physiological dynamic work, are more accepted by the trade and which of the methods that measure metabolic expenditure are easily adapted to technological development. These questions opened the possibility of finding in detail the advantages and disadvantages that are found today in the field of measurement and that are required by these specialists.

The ideas extracted were consolidated and grounded using an empathy map (See figure 4) to identify the relevant insights to create a solution adjusted to the user.

Figure 4. Empathy map



Source: Own Elaboration

The proposed literature review and the compilation of information obtained from the chart presented above, suggest, and approach the group to specify clear needs that they have in the evaluation methods around physiological ergonomics. First of all, it is important to mention that the professionals agree that they must have analyses that are supported by clear and credible data, and demand integrated technological advances with which they can minimize all the operational parts involved in the control of the participant's instrumentation, and the processing of the large amount of data that arise in a test, to be able to concentrate their efforts on the analysis and construction of results with an argumentative and strategic approach.

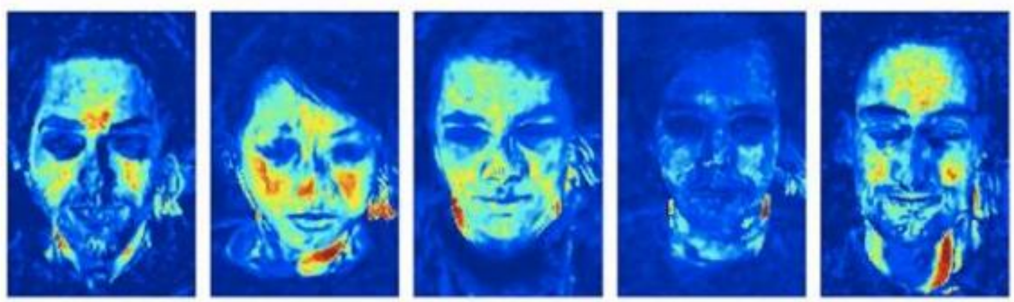
4.2.2 Define

After understanding and defining the scope of the needs raised, it is obtained that: For the measurement of metabolic demands, the indicator approximates a good result in terms of evaluation of an ergonomic risk, this, through the application of methods that stand out in the field and that can be integrated and measured using technological advances, which currently, are highly demanded by experts. Among these methods, the Chamoux Coefficient and FRIMAT stand out.

Today there are common tools for measuring heart rate, based on techniques such as photoplethysmography, as smartwatches. These emit a flashing green LED light on the skin that reaches the blood, which bounces back and returns a very specific image that is analyzed by other sensors. Advances in the area have led to the entry and reception of technological tools, which made possible the actions of photoplethysmography by using images. This technique consists of taking a sequence of images over a region of interest (ROI) and over this sequence processing these images so that each image is transformed into signal data (Fourier Transform). This data is then used to determine the signal to be found.

The regions of interest depend on the vital sign to be measured. In the case of heart rate, they should be regions where the amplitude of perfusion is high. This means that in a person's face these regions can be found in the forehead, the cheekbones below the eyes, and the neck. (See Figure 5)

Figure 5. Perfusion pulse amplitude maps. In red are shown where the amplitude is high and in blue where it is low (Meinzer, Deserno, Handels, & Tolxdorff, 2013).



Source: Meinzer, Deserno, Handels, & Tolxdorff, 2013

The entrance of Industry 4.0, and the technological revolution, has enabled the development of algorithms based on machine learning, which detects faces based on their coordinates within an image, what it seeks is to find the bounding box of each face, the box that delimits its location within the scene. These algorithms are relevant to the development possibilities of the project in question since they enable the integration of face detection and heart rate measurement.

Among the most accurate and outstanding are Viola-Jones and Mobile Net. First developed by Paul Viola and Michael Jones in 2001, the Viola-Jones Object Detection Framework can quickly and accurately detect objects in images and works especially well with the human face (Viola & Jones, 2001). Despite its age, this framework remains a benchmark in face detection alongside many of its CNN counterparts. The Viola-Jones object detection framework combines the concepts of Haar-like features, integral images, the AdaBoost algorithm, and the cascade classifier to create a fast and accurate object detection system.

The MobileNet model is designed for use in mobile applications and is TensorFlow's first mobile computer vision model. MobileNet uses depth-separable convolutions. It significantly reduces the number of parameters compared to the network with regular convolutions with the same depth in the networks. This results in lightweight deep neural networks

4.2.3 Ideate

It is proposed to use the methodology of the six hats, which allows to structure and develop the idea of the degree work, presenting an observation of the different facets of a problem from the different points of view of the members, thus defining the problem and using the 6 hats, where each hat represents a way to find the idea. For further understanding refer to **Appendix 02**.

Using the aforementioned methodology, we propose an application that allows, using computer vision, to measure the heart rate so that analysis of the physiological state of the collaborator can be carried out during the performance of manual lifting and load handling tasks. This tool would present the different results regarding the heart rate values and the ergonomic risk assessment.

For the development of the application, an ergonomic method, an algorithm, design requirements, and its restrictions must be selected. Regarding the ergonomic method, it was necessary to define selection criteria based on the number of instruments and how invasive they are; the ease of data interpretation; costs; adaptability to technological advances; and accessibility by SMEs. Considering these criteria and the interviews conducted with experts, it was concluded that the most appropriate method is the Frimat Coefficient because it only requires a pulsometer and implies medium invasiveness; it is easy to interpret since it is only necessary to score five variables with a table of ranges, assigning to each of these a penalty coefficient whose value ranges between 1 and 6, allowing to obtain the score of the level of effort of the person, since using the Heart Rate the ergonomic risk is obtained, so that it can be integrated and measured by means of technological advances, for that reason its implementation implies very low costs which allow easy accessibility on the part of the SMEs.

It is important to mention that the performance of face detection algorithms is linked to the different factors presented in each context, in this case, we considered criteria that meet the requirements of the design and the need of our user shown in the dimension of empathize, which were: Capture speed with hardware limitations, frontal face recognition, implementation costs and adapted code. So it was necessary to perform a literature review for the selection of the Viola-Jones and MobileNet algorithms for further understanding direct to **Appendix 03**, where it could be determined that the Viola-Jones classifiers have the advantage of performing the identification of a face at a speed of 15 images per second which allows performing the detection in instantaneous time, despite the training time, Viola-Jones has precisely a good capture speed, a shorter calculation time, a faster classification of images and greater ease at the time of implementation.

Under the definition of the imaging photoplethysmography technique described in the defining dimension, it was determined that this technique is the most suitable for the calculation of the heart rate measurement, thus allowing to obtain the result of the ergonomic risk score using the FRIMAT coefficient.

4.2.3.1 Design requirements

The following application design requirements are defined below:

- The application can run on any operating system and must be parameterizable to integrate with a USB camera.
- The application must recognize the initial parameters (images) for data collection and analysis of the ergonomic evaluation method.
- The application is intended to achieve accuracy close to that of a direct measurement device, in this case, a heart rate monitor.

4.2.3.2 Constraints

In addition, the following constraints have been considered:

- For the execution of the experimental design, it is necessary to have a controlled environment about the factors that can affect the good measurement of the application, among these: illumination, camera resolution, and distance between the measuring devices and the worker.
- As a control tool for the illumination factor, it is recommended to avoid or isolate traces of natural light to keep the participant's face evenly illuminated.
- As a control tool for the resolution factor, a 2k definition camera processing 2560 pixels horizontally by 1440 pixels vertically is proposed.
- As a control tool for the distance factor between the measuring devices and the worker, less than 40 cm is proposed

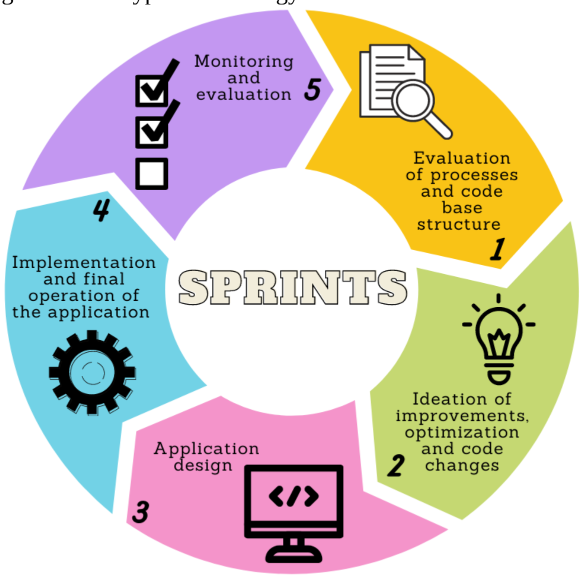
4.2.4 Prototype

To develop the application according to the previously selected methods, it is proposed to use a *Scrum* methodology where the following characteristics are taken into account in the proposed context:

- The work team is made up of a small number of people (4 people), who have basic knowledge of programming and web development.
- The time to develop the solution is limited, so it is mandatory to know how to manage it and carry out actions that effectively achieve the project's objectives.
- The economic resources available are very limited, so it is necessary to use the facilities of the Universidad Javeriana and the resources it could provide us with.

It is proposed to formulate the steps of the methodology, dividing it into a series of components that group a set of techniques, activities, and tools that must be delivered quickly and within short deadlines. The applicability of each of these components is determined by the current state of the project and is determined by the following *Sprints* (See Figure 6):

Figure 6. Prototype methodology



Source: Own Elaboration

For each sprint and the development of an agile framework, two important roles are present:

a. Product owner: degree project coordinator and a student leader.
b. Scrum máster: team leader.
c. Development team members: Working team is composed of the students in charge of developing the degree project.

From the above mentioned, the following is a description of each of the steps used to complete every one of the sprints during the process of creating the application:

1. Refinement of the backlog: The product owner and the scrum master oversee monitoring the work of the development team members where each of the deliverables, doubts, and work done is reviewed. This takes place continuously and is transversal to all the phases mentioned below.
2. Sprint planning: The work team schedules, identifies requirements, and assigns deliverables for each sprint, where, in addition, time limits are established for the fulfillment of the tasks.
3. Stand-up meeting: The work team holds asynchronous meetings every two days to review the work done, prepare the work to be done and review any problems or drawbacks presented in the development of the tasks.
4. Sprint review: It is at the finalization of a sprint to develop the requirements within the established dates and review its correct execution. The scrum master monitors the operation of the code, as well as the work done by providing feedback.
5. Sprint retrospective: During the execution of the sprint, feedback is given on what was done well, what was done badly, and what needs to be improved for each sprint.

STAGE 1: The code used[1] in this stage as the basis for the development of the degree work, was developed by Tristan Hearn at NASA Glenn Research Center which is based on the collection of physiological data that can be estimated using the optical absorption characteristics of oxyhemoglobin. This code works under an individual dual that is placed at about 500cm from the webcam and for its development, the video was recorded in real-time and the heart rate of the subject was manually noted with a pulsometer. Based on this algorithm and the comprehension of its operation and processes, the following stage is followed.

The above code base is licensed under the Apache License, Version 2.0, which states that you may not use the file or the information in it except by the License. Version 2.0 of the Apache License, approved by the ASF in 2004, helps achieve the goal of providing reliable and durable software products through collaborative open-source software development. Within the terms and conditions of its use, this license allows the user of the

[1] https://github.com/thearn/webcam-pulse-detector

software the freedom to use it for any purpose, distribute it, modify it, and distribute modified versions of the software in question.

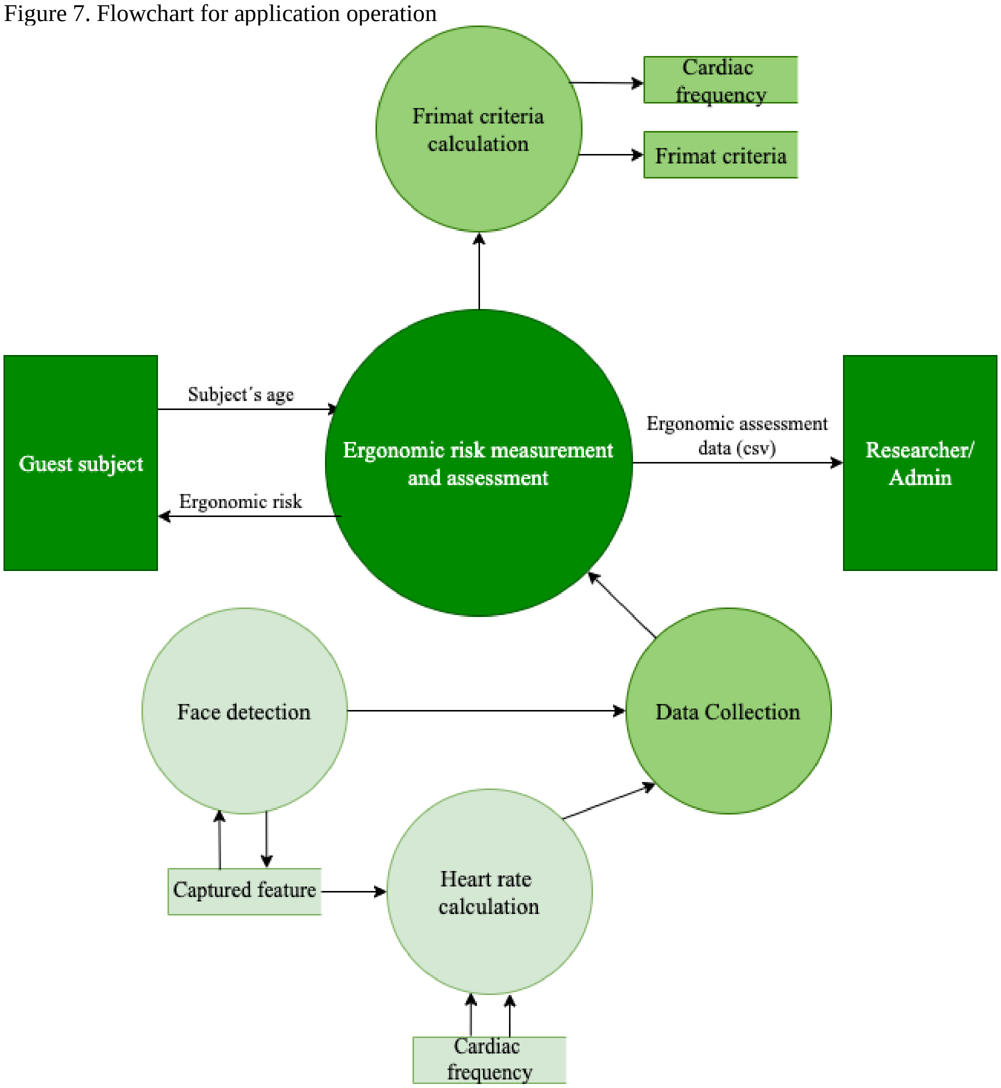
The Apache license is permissive in that it does not require that derivative works (modified versions) of the software be distributed using the same license and only requires that the same license be applied to all unmodified parts and that the code not be distributed for monetary purposes.

STAGE 2: For the development of the degree work and the correct execution of the objectives it is necessary to devise and make changes within the code base about the FRIMAT criterion and the parameters of interest, for this reason, two significant changes are made to the algorithm:

- Implementation of face tracking in the cascade classifier to improve the motion image capture and improve the heart rate measurement while the subject is performing the dynamic task.
- Implementation of an ergonomic module, allowing for calculation of the FRIMAT score and the corresponding ergonomic risk.

STAGE 3: As shown in figure 7 the design of the application for this stage is given by the following Data flow diagram (DFD). The diagram presents three levels of processes, going down from levels where dark green is the main process to light green as the tertiary process.

Figure 7. Flowchart for application operation



Source: Own Elaboration

STAGE 4: After identifying the operation and the variables, the changes and modifications of the algorithm are made by programming in Python under the educational licenses.

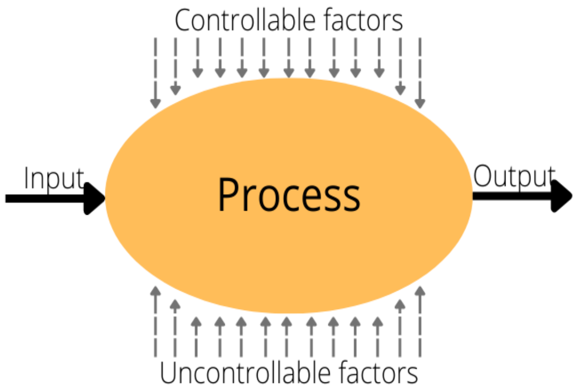
STAGE 5: The monitoring and evaluation of the code performance are carried out by a pilot test, where the system is tested against a direct measurement device (pulsometer) and its error percentage is considered.

4.2.5 Test

As a part of the validation process of the application, it is required to determine a significant sample size for the development of the experiment, this is implemented using a pilot test, which consists of repeated measures experiment **Appendix 04**, where its factors (height, repetition, distance, and phase) and levels were chosen through the ISO 5693-1 standard to recreate dynamic workload environments, to be able to use an appropriate ergonomic evaluation (FRIMAT coefficient). For proper operation, the experiment was planned so that the work team can induce deliberate changes to the process input variable to monitor changes in the output response variable.

Within the design of the experiment, as shown in Figure 8, the presence of controllable and uncontrollable factors in the execution of the application must be considered. Among the controllable factors are height, frequency, weight to be lifted, distance, and light, which was managed within a controlled and closed environment for the execution of the experiment. However, the non-controllable factors are the morphology of the subjects' faces, the use of masks due to the pandemic, and sudden movements or alterations of the person's stability during data collection.

Figure 8. Experimental design graph



Source: Own Elaboration

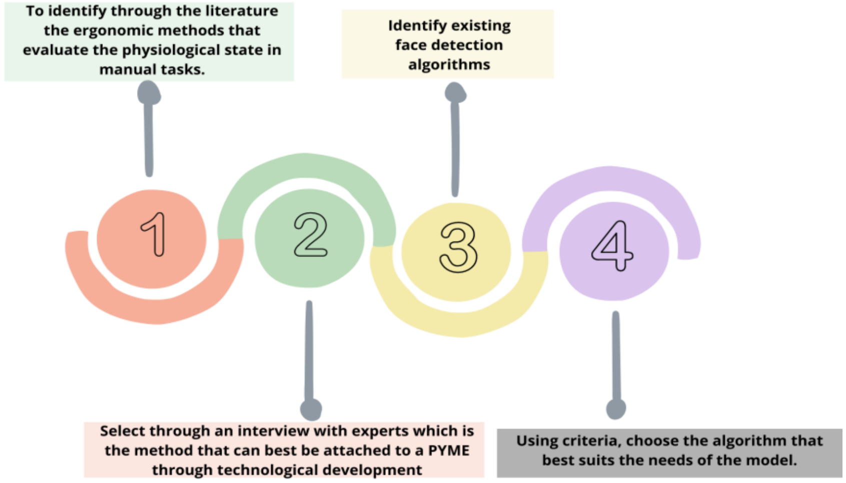
When the sample size is calculated, the experiment is proceeded with following the same process of the pilot test but now considering an additional factor which is "measurement instruments" consisting of the application and the pulsometer, to compare the behavior of the application concerning the pulsometer to determine its efficiency and find the effects of the treatments on the response variable. Therefore, it is necessary to develop different statistical tests, first, the behavior of the data distribution must be verified through a Kolmogorov-Smirnov test, to subsequently verify compliance with the assumption of homogeneity, sphericity, and outliers. Through the development of repeated measures ANOVA, we want to determine if there are statistically significant effects of the factors on the response variability (FC). Finally, the two-sample means (application and pulsometer) from the same population were compared using the paired t-test to check whether the two-sample means are equal or not.

5 Results

5.1 RESULTS OF INTERVIEWS WITH EXPERTS AND SELECTED METHODS (OBJECTIVE 1)

The development and scope of the objective were divided into four phases that bring us closer to the definition and selection of an algorithm that promotes the appropriation of an ergonomic method capable of measuring the physiological state of people when performing manual tasks such as lifting and carrying loads.

Figure 9. Steps in the definition of the algorithm and ergonomics method



Source: Own elaboration

The previous graph in figure 9 is the representation of the methodology chosen for the development of the objective. In the first step, empirical research was carried out in the virtual library of the Pontificia Universidad Javeriana, through which it was found that the most used ergonomic methods for physiological dynamic work are: Chamoux coefficient, FRIMAT coefficient, Electromyography, Theoretical tables of energy expenditure and Spirometry. (**Appendix 01**).

Based on the literature exploration research it was necessary to count on the experience of ergonomics professionals to define which method would be the most adaptable to SMEs, understanding that it should enable technological development, generating ease of interpretation and confidence in the results. For this purpose, qualitative research was applied using the in-depth interview method to 4 experts from the Pontificia Universidad Javeriana and evaluation criteria were defined to approach the general purpose stated, which contributes to the improvement of productivity (**Appendix 04**). The criteria defined and the weight or importance within the evaluation was:

- Adaptability to PYMES (20%).
- Low implementation costs (30%).
- Ease of interpretation of results (20%).
- Number of instruments used in the current measurement and how invasive they are for the evaluated employee (30%).

The results were quantified and evaluated using a prioritization matrix with the following results presented in table 2 (**Appendix 05**):

Table 2. Prioritization matrix of the ergonomics method

ERGONOMIC EVALUATION METHOD	
Total Weighted Score	**Total**
Chamoux Coefficient	4.10
Frimat Coefficient	4.50
Electromyography	2.07
Spirometry	2.23
Theoretical Energy Expenditure Tables	4.15

Source: Own elaboration

The method that best met the evaluation criteria was the FRIMAT coefficient and was chosen for the development of the work in question (See Table 2). This method prioritizes search criteria for existing algorithms with which a non-invasive measurement can be made and show an ergonomic evaluation based on energy consumption by means of heart rate.

Literary research was carried out to show how heart rate can be measured using computer vision and which algorithms are conducive to heart rate detection. As a finding, it was obtained that the most recognized, developed, and implemented object detection algorithms, in this case, face detection, are Viola Jones and Mobile Net. For the choice of one of these two, a qualitative comparison was made utilizing criteria that were chosen thinking about the adaptability of SMEs. These are (1) Accuracy with respect to speed, (2) Recognition of front faces, (3) Implementation costs, and (4) Code adapted to measure the FC (**Appendix 03**).

The results of this last evaluation showed that the algorithm that best suits the needs of the project, considering the constraints, and can provide a clear measurement and evaluation of ergonomic risks in manual activity environments is Viola-Jones.

5.2 RESULTS OF ALGORITHM RE-TRAINING AND INPUT PARAMETERS (OBJECTIVE 2)

Based on the models that were selected for the execution of the algorithm and the estimation of the ergonomic risk, the general performance of the algorithm is established and whether retraining of the algorithm is necessary, in addition to this, the input parameters and the version of the final code of the application are set.

In the first place, a re-training of the algorithm would imply an ability to automatically learn and improve from experience all the general functioning of the code, where by means of machine learning, the code would be able to recognize faces and store them in its memory as data, access them and use them to learn by itself, to carry out an increasingly better and more accurate face recognition process, all this without being explicitly programmed. However, due to the performance of the code depending on the experiment to be performed and the implications of re-training, it is preferable to use face tracking methods incurring less cost, time, and redesign of the algorithm. (**Appendix 06**)

For the reasons mentioned above, a face tracking improvement is implemented to the algorithm. This process consists of two parts: the first one involves the localization of faces, using a face detection system and a face recognition system, while the second one involves the tracking of faces along a sequence of images, that is, a video. Face tracking allows better capture of images and faces of the subjects due to the type of task they are being subjected to, so in addition to saving time in retraining, it improves the overall performance of the algorithm. **Appendix 06** presents in detail the factors of retraining and how the implementation of face tracking is achieved by integrating Viola Jones.

In the second place, another implementation made in the code is the ergonomic risk module, which can calculate the FRIMAT criteria and the ergonomic risk of the person depending on the heart rate presented during the performance of the task. In the same Appendix mentioned above, all the input parameters for the algorithm are presented, including decision sets and variables. The module implemented in the general code of the algorithm is shown below in figure 10:

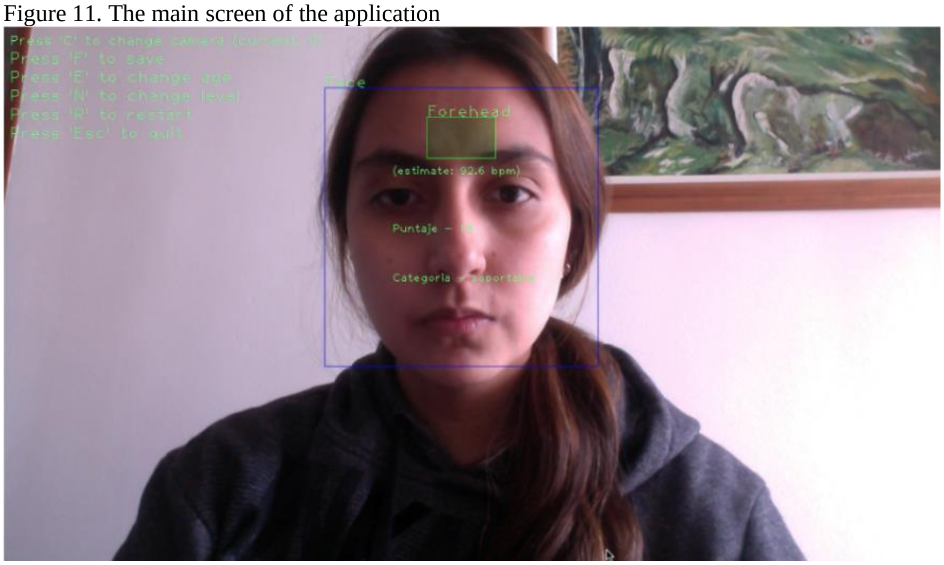
Figure 10. FRIMAT module

```
#frimat module

self.frimat_act = self.fmtfcm + self.fmtfcmax + self.fmtdeltafc + self.fmtccr
fmt = [["carga fisica min", 10],["muy ligero", 12],["ligero", 14],["soportable", 18],["penoso", 20],["duro", 2
value = self.frimat_act
for i in range(len(fmt)):
    j = fmt[i]
    dif.append(abs(value-j[1]))

fmt_min = min(dif)
id_fmt = dif.index(ccr_min)
fmt_select = fmt[id_fmt]
self.fmt_value = fmt_select[0]
self.frimattimes.append((time.time()-self.t0))
self.fmt_list.append(self.fmt_value)
self.frimat_puntaje.append(self.frimat_act)
text2 = "Puntaje - " + str(self.frimat_act)
text3 = "Categoria - " + str(self.fmt_value)
```

Source: Own Elaboration

Finally, in third place, the integrated code is completed by using Python where the application is functional in operating systems such as Windows, Mac, and Ubuntu. In **Appendix 06** are the detailed specifications of the initialization and data collection of the application, as well as the system requirements and explanation of the display. Figure 11 shows the main screen of the application where the data is collected and the ergonomic risk of the person is shown, also, the general code is in the GitHub platform[2] with a license for property protection.

Figure 11. The main screen of the application



Source: Own Elaboration

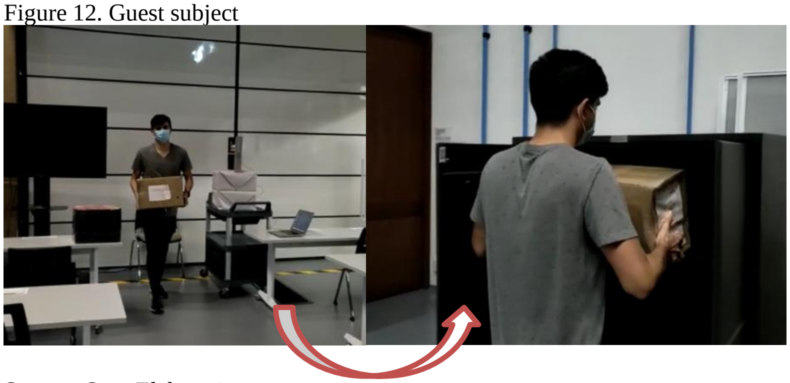
5.3 PILOT TEST RESULTS, SAMPLE SIZE, AND EXPERIMENTAL DESIGN (OBJECTIVE 3)

5.3.1 Experiment design and protocol

Once the objectives and methods to be used are understood, the first approach to the development of the experiment is made by the design of the experiment, implementing a protocol, informed consent, informative video, and pilot test, to clarify the operation of the application and if any changes are required.

Based on the methodology mentioned in previous points, the input variables, output variables, and the process, as shown in the sequence in figure 12 the experiment is performed with male test subjects between 18 and 25 years old, which according to the article 211-H of the Labor Code (2021), in those tasks in which manual handling of loads is unavoidable and mechanical aids cannot be used, workers should not operate loads over 25 kilograms. The subject lifts the load and performs the test run under the parameters mentioned above.

Figure 12. Guest subject



Source: Own Elaboration

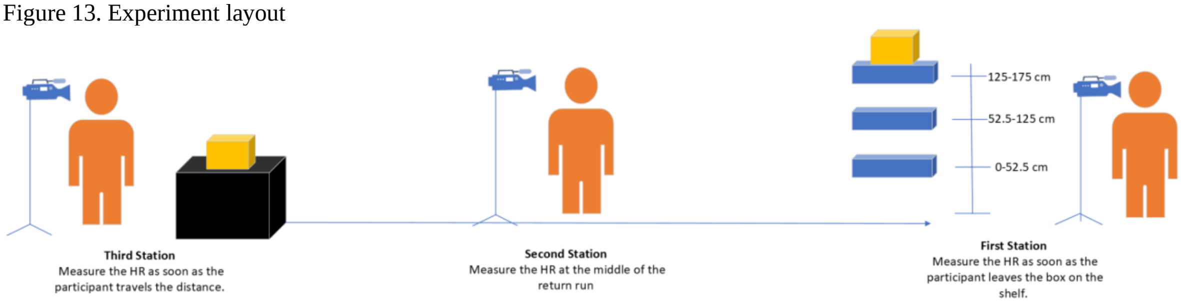
The experiment protocol, which is explained in detail in **Appendix 07**, establishes activities in a clear and precise manner, which allows identifying the response of the measured heart rate under the interaction of different

[2] https://github.com/vergarap-a/Code-degree-project

factors that influence its measurement, about a workstation that presents lifting and carrying loads. In this case, it covers each one of the activities carried out during the development phases (before, during, and after) that tend to the objectivity of the research, all this by means of three phases: self-report, measurement, and closing of the experiment.

The experiment to be performed is based on a repeated measures design explained in detail in **Appendix 07**, where the objective is to show the variation of heart rate in men. The factors to be considered and their respective levels to be evaluated in the experiment are determined from the ISO 5693-1 Standard and the article Heart Rate Analysis related to the variables of height and frequency in weightlifting: height levels, frequency, the distance between stations and measuring instrument. The general design of the experiment is shown below in figure 13.

Figure 13. Experiment layout



Source: Own Elaboration

5.3.2 Pilot test and informed consent

To consider the functionality of the application and to be able to extract the required sample size of subjects, a pilot test was performed before carrying out the experiment, where the application was put into practice for the first time. This pilot test is an experimental trial whose conclusions regarding the application's margin of error were decisive to consider changes in the base code. This test was carried out on four subjects who were given the Informed Consent Form (**Appendix 08)**. These informed consents were filled out and filed by the work team to begin the recognition of the study population.

The pilot test is carried out on the four initial subjects comparing the two measuring instruments used (application and pulsometer). As the objective of this pilot test is to observe the operation of the application, during the test, as can be seen in **Appendix 09**, the data of the total time of duration of the test and the heart rate for both instruments are collected for each of the subjects, with this information by an experimental error treatment, the relative experimental error is calculated expressed as a percentage where the heart rate with the pulsometer is the theoretical value and the heart rate with the application is the experimental value. As can be observed in table 3, the test subjects presented an error less than or equal to 6%, which suggests that the application works correctly without exceeding an error greater than 10%.

Table 3. Papers and keywords

PILOT TEST RESULTS	
Subject	Relative experimental error
1	5%
2	6%
3	5%
4	4%

Source: Own Elaboration

The development of the pilot test can be seen in the following link with an illustrative video of the test: VIDEO

5.3.3 Sample size

Based on the data collected in the pilot test, to obtain significant results for the population, it is necessary to determine a sample size where, after obtaining the observations, the SPSS software was used to demonstrate compliance with the assumptions of normality and homogeneity, followed by a test with repeated measures to observe the size of the effect. Obtaining the results with a confidence level of 95% indicates a sample size of 15 people.

The report corresponding to **Appendix 10** explained in detail the procedure performed in the SPSS and G Power software with the support of what was done in **Appendix 11**.

Based on the above-mentioned protocol and the results of the pilot test, the final report of the experiment is described in **Appendix 12**. In addition, for the execution of the pilot test and later of the experiment, a request was made to subjects who wanted to participate in the experiment voluntarily and who satisfied the required profile.

For the participation of each of the subjects, first, an initial survey was conducted, collecting their general data and their characteristics to know if they complied with the requirements (Input data). Secondly, with the participation of the subject, the informed consent form was signed and all the necessary data on heart rate and FRIMAT coefficient score were collected (Informed consent and app data). Finally, thirdly, the participant completes a satisfaction survey collecting data on their experience during the experiment and their level of satisfaction. All these documents or data are detailed by subject in **Appendix 13.**

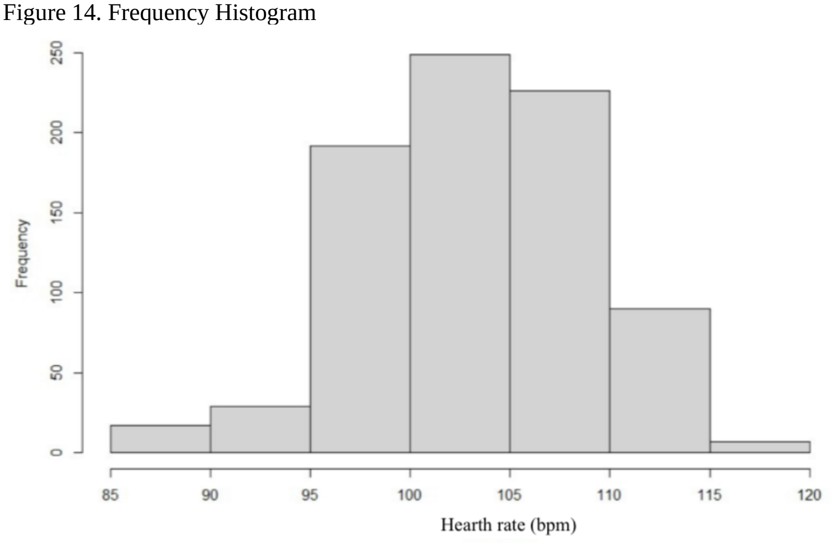
5.4 RESULTS STATISTICAL ANALYSIS (OBJECTIVE 4)

The experiment was performed by each of the 15 subjects under the methodology mentioned above, in the following link you may visualize one of the subjects performing the test as a reference: VIDEOAfter obtaining the database, the statistical tests mentioned in the methodology section were performed using the Rstudio and Spss software, where the following results were obtained (**Appendix 14**) :

Results obtained were based on all data collected and presented in a database (**Appendix 15**) and based on the process carried out in R studio and SPSS as shown in **Appendix 16**.

To first evaluate the assumption of normality, where a Box-Cox transformation was performed to correct the skewness, variance, and nonlinearity of the variables, and thus proceeded to evaluate the assumption of normality by means of the KS test, which yielded a result of $D(0\,.033) - .052, P > .005$ and supported by the QQplot and Histogram graphs, it was assumed that our data approximate a normal distribution.

Figure 14. Frequency Histogram

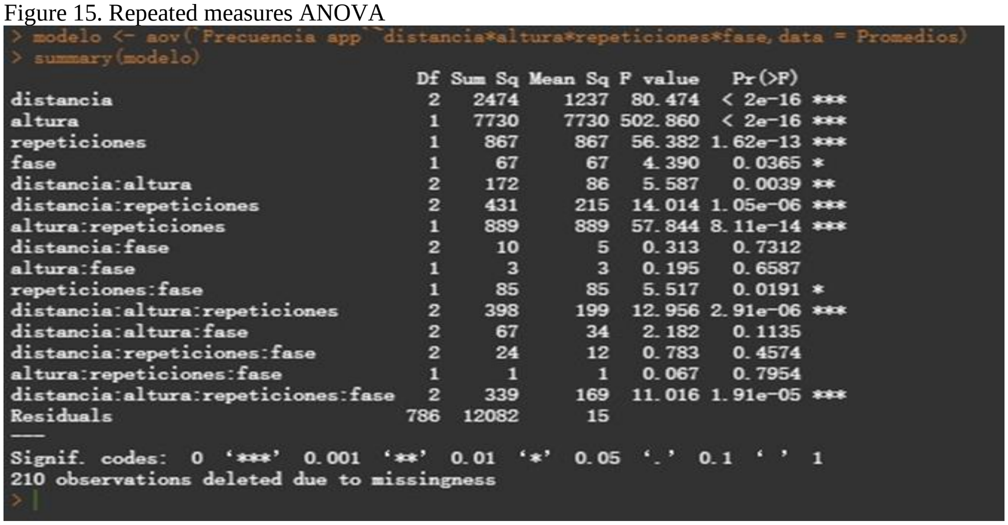


Source: Own Elaboration.

As can be observed in Figure 14, most of the data are represented above the mean, so the average was established as the representative data of all the observations of the FC per treatment applied for each subject. After finding the averages, we proceeded to execute the repeated measures test to study the effects of the factors on the response variable (FC) and evaluate the assumptions of outliers and sphericity, to identify if the test has outliers in the data set and validate if there are significant differences between the variances of the factors.

For the assumption of outliers, a box plot was made in which it was identified that the data are under the limits, so the data are symmetrical. On the other hand, for the sphericity assumption it was found that the factors such as Distance, Repetition and phase are not significant so there are differences between variances, $x2(2) = 9.876, p < .007$; $x2(2) = 8.096, p < .017$; $x2(0) = 0, p < .00$, which the probability of committing a type I error can be 10%, even 20% when the α=0.05, so a corrective index was applied where the α=0.01 was increased, to comply with the assumption.

Figure 15. Repeated measures ANOVA

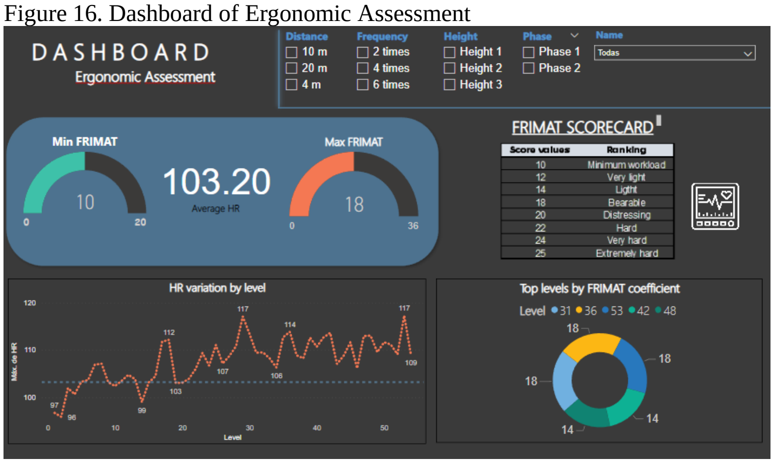


```
> modelo <- aov(`Frecuencia app`~distancia*altura*repeticiones*fase, data = Promedios)
> summary(modelo)
                                   Df Sum Sq Mean Sq F value   Pr(>F)
distancia                           2   2474    1237  80.474  < 2e-16 ***
altura                              1   7730    7730 502.860  < 2e-16 ***
repeticiones                        1    867     867  56.382 1.62e-13 ***
fase                                1     67      67   4.390   0.0365 *
distancia:altura                    2    172      86   5.587   0.0039 **
distancia:repeticiones              2    431     215  14.014 1.05e-06 ***
altura:repeticiones                 1    889     889  57.844 8.11e-14 ***
distancia:fase                      2     10       5   0.313   0.7312
altura:fase                         1      3       3   0.195   0.6587
repeticiones:fase                   1     85      85   5.517   0.0191 *
distancia:altura:repeticiones       2    398     199  12.956 2.91e-06 ***
distancia:altura:fase               2     67      34   2.182   0.1135
distancia:repeticiones:fase         2     24      12   0.783   0.4574
altura:repeticiones:fase            1      1       1   0.067   0.7954
distancia:altura:repeticiones:fase  2    339     169  11.016 1.91e-05 ***
Residuals                         786  12082      15
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
210 observations deleted due to missingness
>
```

Source: Own Elaboration.

With the fulfillment of the assumptions, the results of the repeated measures ANOVA were analyzed (See Figure 15), where it was observed that factors: Distance, Height, Repetition, and the combinations: Distance-Height; Distance-Repetitions; Height-Repetition, Distance-Height-Repetitions; Distance-Height-Repetition-Phase, significantly affect the response variable (HR).It is important to mention that the combination Height-Repetitions is the one that presents the greatest effect on the response variable $F(1,786) = 57.84, p = .00$, this combination is corroborated by the study conducted by Saavedra-Robinson et al., (2021) which concluded that the treatment that considers the interaction between lifting frequency and height leads to an increase in heart rate, being consistent with the analysis of variance that rectified the effect of this interaction.

Figure 16. Dashboard of Ergonomic Assessment

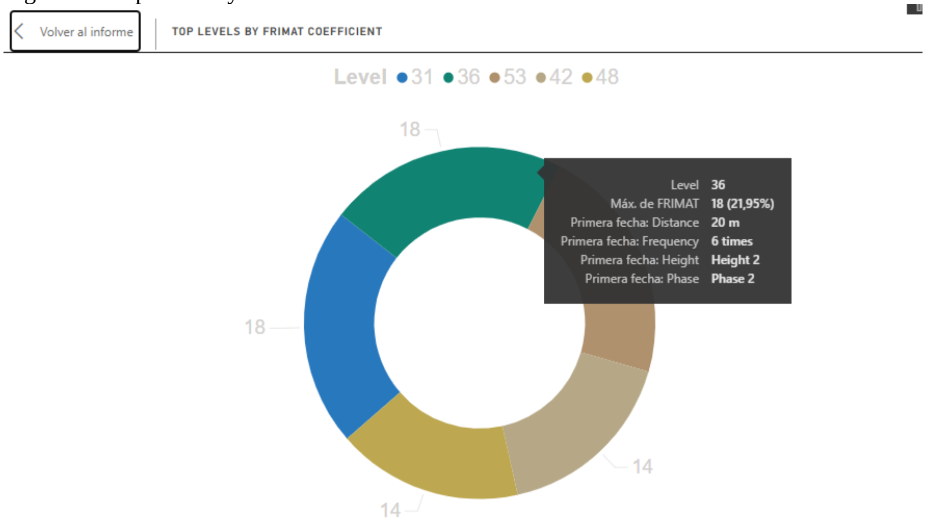


Source: Own Elaboration.

To better understand and analyze the data, a dashboard was created in Power Bi (**Appendix 17**) to dynamically visualize the behavior of the response variable and the ergonomic coefficient. As shown in figure

16, a graph of HR variation by level, the top levels by Frimat coefficient, and the Frimat scorecard was generated depending on the factor.

Figure 17. Top levels by FRIMAT coefficient



Source: Own Elaboration.

As can be observed in Figure 17 the values obtained under the FRIMAT coefficient, for most treatments, a rating of "minimum workload" was obtained. In treatments 31,36,42,48, and 53 the rating of the task as minimum load decreases, and the rating of "very light", "light" and "bearable" increases.

Figure 18. Paired t-test

```
        Paired t-test

data:  BaseDatosComparacion$`Frecuencia app` and BaseDatosComparacion$`Frecuencia Pulsometro`
t = 1.21, df = 1040093, p-value = 0.2263
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -0.002210633  0.009343779
sample estimates:
mean of the differences
            0.003566573

>
```

Source: Own Elaboration

In addition, the effectiveness of the application was evaluated, for this, the application was compared with the direct measurement equipment (pulsometer), where the average error of the application was calculated, this gave as result 2. However, the paired t-test (See Figure 18) was applied to evaluate if the comparison is significant, in this test it was found that the mean between the two measures is equal, $t(1040093) = 1.21, p = .2263, d = 0.035, IC95\%[-.0022, .009]$, which indicates that the data taken by the application do not present significant differences for those taken by the pulsometer.

The heart rate monitor is assumed as the validation element for the efficiency of the application. According to the study by García et al., (2017), it was considered that the measurement equipment has already been validated previously and it can predict the heart rate with a margin of error of 5%, so with the application we want to closely reach the confidence level of the pulsometer. With the statistical test performed previously, it was confirmed that there are no significant differences between the data taken, thus, it was concluded that the application has a 97.5% efficiency concerning the direct reading equipment.

6. Impact measurement

Technical impact: The adoption of technology in small and medium-sized companies in Colombia responds to and resolves in large part the need to be agile and efficient in the face of current changes. This application allows directing a process that favors the optimization of time and results, which indirectly allows generating a competitive advantage of positioning in the market. It improves productivity by reducing errors and human biases in the evaluation, reducing manual work, focusing strategic thinking, and improving informed decision making, all this with the same number of resources, in this case, computers.

Economic impact: Nowadays, SMEs are constantly seeking to optimize their resources to obtain better results. Not having the complete availability of their human resources due to absences caused by work-related illnesses has implications on business productivity by not achieving greater competitiveness in the market, i.e., an increase in expenses that can be prevented through the efficient and effective results provided by the application. On the other hand, the acquisition of resources for companies that are starting up or that have a reduced staff represents an expense that can generate a burden or decrease in income, and it is here where the use of resources plays an important role, representing a saving when acquiring pulsometers that can be supplied by computers that the company already has.

Social Impact: The application allows workers to have a healthier lifestyle. Thanks to the fact that the application constantly displays the ergonomic risk on the main screen, the worker can review it during his work activity, observing those moments in which he is at risk and must stop or moderate his work, thus preventing occupational diseases, which reduces the need for medical treatment. In addition, it is worth noting the positive impact on the community and the family nucleus of the fact that workers have tools to ensure their health.

Environmental Impact: Finally, there is an environmental impact in the development of the application, related to the use or disposal of resources and environmental sustainability. Instruments such as the pulsometer for direct measurement and ergonomic evaluations indirectly involve the use of batteries or electrodes that electronically control the pulsations of the heart, however, for their correct functioning, these batteries have a limited number of charge cycles so they must be replaced occasionally.

Batteries discarded by these devices can cause damage to the environment, since when they are in the trash, they lose their cover and release the metals they contain, leaching into the soil, and causing harmful substances to reach rivers. The toxic substance known as mercury can contaminate water sources and sicken all living beings, including those consumed by humans, causing disease. Although the batteries of the pulsometer are smaller in size, the massive use of these instruments by companies or individuals may imply greater contamination. Therefore, the use of the developed application allows not wasting resources for the manufacture of these instruments or their use, such as batteries, contributing to the care of the environment.

7. Constraints and recommendations

After completing the process of running the experiment and subsequently collecting and analyzing the data, different limitations were found during the experiment. First, while the experiment was being carried out, it was identified that one of the controllable factors, in this case, lighting, sometimes did not allow the correct development of the application. Although there was a lighting environment of less than 150 lx, the intense sunlight and nearby external lights affected the performance of the application, affirming that the application obtained better results in environments that did not exceed the mentioned lux.

Secondly, following the same line of limitations during the execution of the experiment, the morphology and stability of the person for data collection by the application sometimes caused the application to fail. On the one hand, with the operation of the application based on frames and face tracking, the forehead of the subject had to be completely clear, without marks, hair, or accessories that could distort the visibility of the forehead, additionally, subjects with small foreheads were not recognized by the application. On the other hand, although bases were built to support the subject's head and eliminate any possibility of instability, some subjects presented sudden movements and unstable during data collection, resulting in outliers in the analysis of the data.

Thirdly, we identified a limitation generated by the pandemic and health contingency presented by Sars Covid 19. In addition to the fact that many people who wanted to participate in the experiment could not attend due to the limitation of the pandemic, it was identified that the mandatory use of masks affected the good performance of the application, where masks with colors such as black, white, or multicolor were not recognized in the application as a valid face, so only light blue masks had to be used for the face to be identified.

Finally, a limitation was identified during the data analysis. It was planned to use the SPSS software tool for data analysis, however, after doing the whole process in this software, having a large amount of data and observations per subject, inconsistencies were recognized in the results that the program returned, where it did not take all the data and did not satisfy the required assumptions of the tests performed. For this reason, it was necessary to reprocess and reanalyze the data in the most powerful and flexible computational language that would allow a better understanding of the behavior of the data. In this case the reprocessing was done in R, a more powerful language for scientific, numerical, and statistical calculations, taking more time than expected.

Therefore, primarily, on the one hand, it is recommended to continue improving the application code and face recognition by computer vision under the Apache license. The implementation of other types of algorithms can be done and observe their behavior against the limitations of light, morphology, instability, and use of masks, likewise, improvements to face recognition can be implemented using tools such as unsupervised machine learning where the code is allowed to make clustering of faces through the recognition of patterns in them. On the other hand, it is recommended for this type of data analysis to make direct use of programming languages such as Python, R, or SQL to avoid setbacks or prolonged use of time.

This kind of application, like the one elaborated in this degree project, opens the way to a holistic vision of different uses. For this reason, it is recommended to extend the study of the computer vision algorithm and the collection of heart rate, to new ergonomic measurement tools, implementing new assessment methods that can control the physical state of the person and even detect health problems and feelings of physical or emotional tension of the person such as stress.

8. Discussion

Industry 4.0 breaks paradigms of connectivity and relationship in the supply chain of a business model, proposing a world in which devices are interconnected all the time and allowing interpretation of data in real-time. (Tapia, 2014). This application comes to an important role as it contributes to the concept by integrating models that unite concepts of online ergonomic evaluation, exalting the assertiveness of the information and maintaining real-time progress that allows strategic and accurate decision making.

Achieving almost immediate decision making and being able to do it, with new development, through different mobile devices, makes flexible the need to have a single place of evaluation and allows constant monitoring of the health status of employees. In addition, the application achieves massive data collection, generating a history of information, opening the way to the use of tools that support storage, and statistical modeling, and allowing the analysis and visualization of information. This not only generates support but also enables the expert to evaluate trends and limits associated with the level of hardship present in a workplace.

It is key then, to understand that in our hands is to achieve and promote the advancement of these technologies that not only empower and give added value to a company, in terms of sustainability and labor welfare thus increasing their productivity levels but also making profitable the business model that you have, in ergonomics concepts, as it allows evaluations with existing tools and reduces the operational activity of the expert generating process optimization. Therefore, companies in general, and SMEs, must be in constant research, renewal, and training if they want to remain relevant. Indeed, these are the essential keys that will enable companies and industries to remain competitive in the marketplace and survive in the face of what is to come. (Tapia, 2014)

9. Conclusions

The approach and understanding of the current needs in the area of ergonomic evaluation and well-being of the collaborator through literature and the expertise of professionals in ergonomics were key to finding opportunities for technology input in the current evaluation methods for jobs that are considered dynamic. Understanding the different ways to measure the metabolic rate, it was found that the heart rate was the most appropriate physiological measurement variable, due to its adaptability to technological models based on face detection, where it was found that the base algorithm to work with was Viola Jones, being the algorithm with more benefits and adaptability to the requirements of the experiment.

Based on the selected ergonomic evaluation method and the most pertinent algorithm, we redesigned from the base code an application capable of collecting heart rate and making an ergonomic evaluation of the Frimat criteria. The correct use of programming languages allowed, on the one hand, the development of improvements to the code within the established time, resulting in a significant improvement in face recognition, and, on the other hand, correct integration of computer vision technologies with ergonomic methods. The obtained application works under a python programming language in Windows, Mac OSX, and Ubuntu operating systems, with a quick start system that allows the user to collect information from employees in a fast, simple, and accurate way.

After programming the application and conducting a pilot test that will yield the necessary results to subsequently design the experiment, it was necessary to create a protocol detailing the specific activities to be performed in this test for 4 subjects. The good organization of this test achieved the optimal collection of heart rate data so that the successful operation of the application was observed, since, when compared with the data taken with the heart rate monitor, an experimental error of less than or equal to 6% was obtained, which indicated that it was possible to perform an experiment that would give us reliable results.

Under the repeated measures ANOVA it was obtained with a 99% confidence that the factors Distance, Height, Repetition and the combinations: Distance-Height; Distance-Repetitions; Height-Repetition, Distance-Height-Repetitions; Distance-Height-Repetition-Phase, significantly affect the response variable (FC). On the other hand, under a paired t-test it was possible to conclude with a confidence of 95% that the variances of the means of the application and the pulsometer are equal, identifying that the efficiency with which the application works to the pulsometer is 2.5%, and an efficiency of 97.5%.

10. Regarding Appendixes

Table 4. Appendixes

Appendix	Appendix Name	Source	Type of File
1	Empirical Research Report Ergonomic Methods	Own Elaboration	PDF
2	Six Thinking Hats	Own Elaboration	PDF
3	Comparative analysis between face detection algorithms	Own Elaboration	PDF
4	Development Of Expert Interviews and Interviews Transcripts	Own Elaboration	PDF
5	Ergonomic method decision matrix	Own Elaboration	PDF
6	Algorithm for heart rate detection by computer vision for dynamic tasks	Own Elaboration	PDF
7	Heart Rate Measurement Protocol	Own Elaboration	PDF
8	Informed Consent	Own Elaboration	PDF
9	Pilot Test	Own Elaboration	Excel (.xlsx)
10	Sample Size Report	Own Elaboration	PDF
11	Output software sample size	Own Elaboration	Zip
12	Experimental Design Report	Own Elaboration	Zip

13	Subject Data	Own Elaboration	PDF
14	Statistical Tests Result Report	Own Elaboration	Excel (.xlsx)
15	Data Base	Own Elaboration	PDF
16	Statistical Test process (R studio, SPSS)	Own Elaboration	PDF
17	Dashboard Ergonomic Evaluation	Own Elaboration	.Pbix

Source: Own Elaboration

References

Ballesteros Puerto, L. G. (2014). *Desarrollo de un dispositivo de bajo costo para monitoreo de ritmo cardiaco de bebés por medio de procesamiento de imágenes*. Universidad de los Andes.

Bauters, K., Cottyn, J., Claeys, D., Slembrouck, M., Veelaert, P., & van Landeghem, H. (2018). Automated work cycle classification and performance measurement for manual workstations. *Robotics and Computer-Integrated Manufacturing*, *51*, 139–157. https://doi.org/10.1016/j.rcim.2017.12.001

Bevan, S. (2015). Economic impact of musculoskeletal disorders (MSDs) on work in Europe. In *Best Practice and Research: Clinical Rheumatology* (Vol. 29, Issue 3, pp. 356–373). Bailliere Tindall Ltd. https://doi.org/10.1016/j.berh.2015.08.002

CCS. (2022). *Durante el primer trimestre de 2022 se redujeron las tasas de siniestralidad laboral en el país*. https://ccs.org.co/portfolio/durante-el-primer-trimestre-de-2022-se-redujeron-las-tasas-de-siniestralidad-laboral-en-el-pais/

Collado Luis, S. (2008). Prevención de riesgos laborales principios y marco normativo. *Revista de Dirección y Adminitración de Empresas*, *15*, 91–117.

David, G., Woods, V., Li, G., & Buckle, P. (2008). The development of the Quick Exposure Check (QEC) for assessing exposure to risk factors for work-related musculoskeletal disorders. *Applied Ergonomics*, *39*(1), 57–69. https://doi.org/10.1016/j.apergo.2007.03.002

Diego-Mas, J.-A., Poveda-Bautista, R., & Garzon-Leal, D.-C. (2015). Influences on the use of observational methods by practitioners when identifying risk factors in physical work. *Ergonomics*, *58*(10), 1660–1670. https://doi.org/10.1080/00140139.2015.1023851

García, J. D., Pérez, F. J. G., Gil, M. C. R., Mariño, M. M., & Marín, D. M. (2017). Estudio de la carga interna en pádel amateur mediante la frecuencia cardíaca. In *Apunts. Educacion Fisica y Deportes* (Issue 127, pp. 75–81). Instituto Nacional de Educacion Fisica de Cataluna. https://doi.org/10.5672/apunts.2014-0983.es.(2017/1).127.08

Gonzales, H., & Velásquez, S. (2019). *Reconocimiento facial utilizando viola-jones y patrones binarios*.

Greene, R. L., Azari, D. P., Hu, Y. H., & Radwin, R. G. (2017). Visualizing stressful aspects of repetitive motion tasks and opportunities for ergonomic improvements using computer vision. *Applied Ergonomics*, *65*, 461–472. https://doi.org/10.1016/j.apergo.2017.02.020

Instituto Canario de Seguridad Laboral. (n.d.). *Los trastornos musculoesqueléticos de origen laboral*.

Krause, W., & Schutte, C. (2015). Developing Design Propositions for an open Innovation approach for SMEs. In Intergovernmental Panel on Climate Change (Ed.), *Climate Change 2013 – The Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 1–30). Cambridge University Press. https://doi.org/DOI: 10.1017/CBO9781107415324.004

MassirisFernández, M., Fernández, J. Á., Bajo, J. M., & Delrieux, C. A. (2020). Ergonomic risk assessment based on computer vision and machine learning. *Computers and Industrial Engineering*, *149*. https://doi.org/10.1016/j.cie.2020.106816

Parra, E. (2015). *Aceleración del algortimo de Viola-Jones mediante rejillas de procesamiento Masivamente paralelo en el plano focal*.

Piraquive, I. (2018). *Alcances del diseño y la ergonomía en las pymes Análisis del sector calzado del Barrio Restrepo de la ciudad de Bogotá*.

Ruiz, S. G., María, J., & Sánchez, M. (2017). *Aplicación de detección de ritmo cardíaco mediante análisis de secuencias de vídeo*.

Saavedra-Robinson, L. A., Paredes-Astudillo, Y. A., & Quintana, L. (2021). Análisis de la Frecuencia Cardiaca relacionada con las variables de altura y frecuencia en el Levantamiento de cargas. *Archivos de Prevencion de Riesgos Laborales*, *24*(1), 34–46. https://doi.org/10.12961/aprl.2021.24.01.04

Sánchez, G., & Solano, N. (2017). *Efecto de las enfermedades laborales sobre la productividad en la dirección seccional Santander de la fiscalía general de la nación*. Universidad autónoma de Bucaramanga.

Sivakumar, M., Saranprasath, N., Sridharan, N. S., & Shanmuga Praveen, V. (2021). Retraction: Comparative analysis of CNN and Viola-Jones for face mask detection. In *Journal of Physics: Conference Series* (Vol. 1916, Issue 1). IOP Publishing Ltd. https://doi.org/10.1088/1742-6596/1916/1/012043

Wu, H.-Y., Rubinstein, M., Shih, E., Guttag, J., Durand, F., & Freeman, W. (2012). *Eulerian Video Magnification for Revealing Subtle Changes in the World*.