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Thermography: an a assessment tool in the Ergonomic Analysis of a Work Station in the Foundry Industry

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Abstract

Thermography has been increasingly used in various areas of knowledge. Equipment, components and systems are still the main focus of this technique. Currently items of thermographic equipment have become more accessible thus enabling new applications. This article explores thermography as a means to make an ergonomic evaluation of a job in metal casting, an area that involves activities that are energy sapping wearisome and uncomfortable for workers. Use was made of the method of macro-ergonomic analysis of work proposed by Guimarães (1998), in a medium-sized industry, in the sectors of manual molding and finishing. 27 workers were evaluated. Based on this method and statistical analysis, the finishing sector was identified as the most critical one, in which thermograms were collected during the work activity of a volunteer. There was a 1.8 oC increase in the average skin temperature of the regions examined, before and after 1.5 hours of activity. This variation represents a great exertion required in the workplace. The results indicate that the analysis of thermograms assists in the evaluation of work activities, as the physical exertion expended is quantified. This technique can potentially aid the study and improvement of jobs in the industry, particularly those that most weary the human body.

Keywords: ergonomics; thermography; physical load; smelting.

1 Introduction

The use of thermography can still be considered new and even innovative because new applications for the technique have emerged or were only possible in recent years due to the improvement in the quality of thermal images generated by modern infrared cameras.

Industrial applications are still the main focus of this technique such as those linked to industrial maintenance in detecting defects in electrical and mechanical components. Another industrial application is to check thermal insulation systems of pipes and tanks and a further on is to analyze thermal leakages from products such as oven stoves for household use.

In recent years, new studies and a downward trend in the cost of pieces of equipment that generate thermal images have led to new possibilities. Specific applications of thermography carried out in ergonomics can be seen (Ashwin (2007) and Guimarães, Fischer and Bittencourt (2004).

The objective of this article is to analyze jobs in metal smelting, an area that workers find is energy sapping and uncomfortable, especially for non-automated molding operations, the discharge of liquid metal, emptying casting molds and for finishing. The company studied, which is within the foundry industry, is of medium size and is located in the state of Paraná, in the south of Brazil. The main focus of this study was the use of thermography as a tool for ergonomic evaluation.

2 Theoretical Background

William Herschel proved that heat could be reflected and refracted under certain conditions. His son, John Herschel, succeeded in generating an image using solar radiation. He called this image a thermogram, a term still used to describe the image generated by thermal radiation (Ring, 2007).

Known of since the 1970's, thermography has received new attention in recent years. It is a technique that captures radiation in the long infrared band (7.5 to 13 μm) emitted by the human body, thus providing an image of the thermal distribution of the skin surface. The temperature of the skin, under carefully controlled environmental conditions, is mainly influenced by its microcirculatory activity and by the production of heat conducted to the surface which has been generated in deeper tissues. Thermography has more recently been called Infrared imaging (II), due to the new ultra-sensitive infrared detectors (Brioschi *et al.*, 2007).

The maintenance of body temperature by the human body is a complex phenomenon. Man is homeothermic and produces heat that should be lost to the environment. The interface between the environment and the production of heat is the skin. This dynamic organ is constantly adjusted to balance the external and internal conditions, thus offsetting the physiological demands of the body. Sympathetic motor fibers control cutaneous microcirculation by means of vasoconstriction or vasodilation, causing the skin to be irrigated to a greater or lesser extent. This phenomenon of controlling the transfer of heat through the skin is defined as thermoregulation and is dependent on controlling the autonomic nervous system. Cutaneous thermometry by infrared imaging is the most efficient way to study the distribution of skin temperature today. It is a diagnostic method that evaluates the microcirculation of the skin and, indirectly, also evaluates the sympathetic nervous system closely related to the skin (Brioschi *et al.*, 2003).

The use of thermography in medicine is broad and includes the detection of diseases of the breast, lumbar disk hernia, and deep vein thrombosis. Cherkas *et al.* (2001) examined the use of thermography to diagnose Raynaud's phenomenon, and this was shown to be promising. There is a recent renewed interest in using infrared images for medical use in the detection of tumors (QI *et al.*, 2000).

Yoon *et al.* (2004) proposed an algorithm for analyzing thermal images with a view to identifying physiological problems in the forearm region. They conclude that by analyzing the images it is possible to estimate the thermal features of human forearms efficiently.

A study seeking the recognition of facial expressions using geometric characteristics based on thermal infrared images is given in Jiang *et al.* (2005). This study shows that facial temperature always changes at the same time as the expression does. It also showed that it is possible to recognize facial expressions based on thermal imaging, which can be used when monitoring in real-time and thus help medical diagnoses.

Ring *et al.* (2004) present a database for the distribution of temperature of the skin in normal human beings who are 10-75 years old. They used digital infrared thermal imaging. Despite the many different applications and studies, a normal base was not found to be available, especially for clinical use in hospitals.

Merla and Romani (2006) describe an innovative method of obtaining quantitative diagnostic tools based on thermal images. They show that high resolutions of infrared thermography, combined with modeling bio-heating, have a wide variety of applications. With such studies, it is becoming possible to give a better and more complete description and understanding of the functional processes involved in the presence of interferences such as cutaneous thermoregulation. The successful application of diagnostic procedures needs to be supported by several important elements: effectively designated diagnostic protocols and paradigms; control of accuracy and standardization of experimental conditions; analysis of appropriate data and image processing; and a multimodal approach, if possible. All of these are equally essential for a quantitative and effective infrared thermal image.

However, the infrared technique has been applied with equal or greater success in monitoring peripheral circulation in the presence of disorders of the tissues. Variations in temperature due to inflammation in

the arms, hands, legs and feet are detected by the influence of the "thermal reservoir" formed by the trunk of the body (Jones; Plassmann, 2002).

According to Jones and Plassmann (2002), thermal images for medical use are acquired in various ways and are classified according to the temporal sequence of the images. They report four methods which are described below:

- Method 1: A static image of the patient is acquired at a given instant and is used to identify hot and cold spots, emphasis being given to areas of the image where the temperature gradients are high or to measure asymmetries in the distribution of skin temperature
- Method 2: Static images are captured at times which are separated by a substantial time interval of an order such as to monitor the progress of an infirmity or a treatment or even to detect the severity of inflammation (heat is one of the five classical symptoms of inflammation)
- Method 3: A series of images is captured for a period of minutes to monitor the recovery of skin temperature after an external provocation such as thermal stress (heat or cold), mechanical stress (vibration) or chemical stress (vasodilators or vasoconstrictors)
- Method 4: A series of 1,024 images is captured at a rate of 100 frames per second for 11 seconds during which time the patient is seated and holds his/her breath

According to Ashwin (2007), human thermal images obtained from infrared cameras:

- Establish a baseline measurement to evaluate the ergonomics program of companies
- Assist in evaluating the risk of injuries that arise from work
- Help determine the worker's physical capacity in relation to the physical requirements of the activity
- Identify work-related osteomuscular disorders (RSI-WRMD) efficiently
- Help reduce indirect costs such as false complaints

The use of thermal imaging technology is fairly recent. In the literature, new applications are gradually emerging. Linked to cutaneous thermometry, much has been related to the identification and diagnosis of problems and diseases. However, with respect to ergonomics, especially the analysis of workload and exertion, the number of references is still relatively small. This paper seeks to make use of this application that can both assist health at work professionals as well as those directly related to ergonomics, thus minimizing the suffering of workers who carry out exhausting or even superhuman activities.

A study on the exertion involving workload performed by employees carrying out their routine activities, can be found in Guimaraes, Fischer and Bittencourt (2004). In their study, in addition to other techniques, they used thermography to prove and even to quantify the variation in the skin temperature of linesmen before and after they performed the task of climbing poles. It was based on that study that the motivation came to undertake this study in the field of metal casting.

3 Company Under Study

The company studied is a small foundry in Brazil. It manufactures parts in gray and nodular iron. It started up in 2001, and serves clients nationally and in Chile and Argentina. It is structured to focus on the production of technical parts for the automotive and agricultural industries, real estate, heavy machinery for railroads, sanitation and telecommunications. It also supplies its products to Brazilian organizations in the segment of household appliances, and the manufacture of silos and warehouses.

The built area of the company is 4,600 m^2 and includes two furnaces, one is of the cubilôt type and the other by electric induction, a molding machine, modeling and a laboratory for evaluations and product development. It has approximately 38 employees and works in two shifts (05:00 - 14:00 and 09:00 - 18:00).

4 Method of Macroergonomic Intervention

The analysis of the foundry employees' work covered the first three steps (assessment, diagnosis and proposing solutions) of the method of macro-ergonomic analysis of work proposed by Guimarães (1998), which provides for the workers' participation in all project phases. The method adopted also follows the study by Guimarães, Fischer and Bittencourt (2004) who made an assessment of the workload imposed by three systems on power linesmen regarding how they climb up and down electricity poles. We also used the article by Bridges (2005) which deals with the incidence of pain in the lower back for a better understanding of working conditions in the company studied.

It should be noted that this study is focused on the use of thermography to evaluate workload in industry. As indicated in the section on the theoretical background, applications for measuring and analyzing thermal images generated by irradiation of human skin temperature are still recent and concentrated in medical applications, with trials in controlled environments. The phases and conduct of the research are described below.

4.1 Ergonomic Evaluation

A preliminary survey was carried out on visits to and observation of the workplaces. The industrial director, the materials engineer and workers were encouraged to raise problems relating to the working conditions of the workers, who were also heard.

According to the Industrial Director, until 2005 the activities were performed without rotating jobs with regard to the molding sector, in which most of the employees (approximately 20) are concentrated. There was a high rate of complaints particularly about back pain and consequent removal of workers from such posts. After this period to the present, a rotation of activities was implemented in this sector and there was a significant reduction in the index referred to. It was observed that this rotation exists only in the molding sector. In the other sectors, the jobs are fixed.

Following Pontes (2005), work in the manual molding sector in the company studied can be divided into seven phases: fashioning and compacting the sand molds; opening the forms; transporting the crucible and placing the liquefied metal in the molds; removing the product after it has cooled (semi-finished); and finally the preparation of sand for re-use.

During the preliminary fieldwork, it became clear that the manual molding sector should be dealt with in the research, even though conditions have improved in recent years. Another sector that attracted the attention of the researchers was the finishing sector, particularly those workers who remove burrs in grinding stones. The environment is noisy and the removal of burrs in emery stone requires considerable compression exertion against the grind-stones.

The study was limited to the staff of the manual molding and finishing sectors because the other sectors showed no signs of overload. The methodological tools used in this phase were observation of workplaces, a camera, interviews and questionnaires.

4.1.1 Ergonomic Constraints in the Manual Molding Sector

The manual molding workers carry out their activities on a rotating basis, which according to the industrial director has reduced the problem of sick leave and transfers. The ovens are in the same environment as the molding. Because the ovens are relatively small and there is good convection, temperatures do not reach very high levels anywhere in this sector.

The activities demand physical exertion especially when handling molds when they are being fashioned. Larger pieces can weigh up to 150 kg. At the time of demolding the weight is increased by the solidified metal. During the manufacture of the molds, workers use an awkward posture, which was the causal factor for higher rates of pain in the lower back and sick leave/ transfers until 2005, prior to which there was no rotation of duties, as reported in Pontes (2005).

Loading the crucible also requires considerable exertion. Approximately 70 kg are distributed between two workers. The activity does not appear to be critical, because it is fast (lasting a maximum of 30 seconds). It is found that one of the workers has only one point at which to hold the crucible with one hand. This worker walks all along his route with the load and his posture out of balance.

The main safety aspect is the risk of burns, a risk inherent in the activity. The liquid metal, around 1500 ^{0}C, offers serious risks from when it is unloaded from the furnace to the crucibles, through its transport and casting in the molds.

4.1.2 Ergonomic Constraints in the Manual Molding Sector

The activities of those who work on finishing are not performed in rotation. What is most striking is the high level of noise, in the range of 108 decibels. All employees use appropriate ear muffs. The exertion in grinding is the most tiring. The worker needs to press the part with considerable force to remove the burrs. Some parts are heavy, around 30 kg. Their posture is static which together with the use of protective masks suggest an activity that is uncomfortable and exhausting.

Safety is not really a problem in this sector. The use of goggles, masks and gloves minimize the likelihood of injuries should metal particles spray out, which is the main risk factor in this location.

4.2 Diagnostics

The ergonomic assessment conducted served as the basis for identifying activities that require greatest attention in the study. As previously mentioned, the other sectors showed no signs of overload. The study was limited to the manual molding and finishing sectors, particularly the activity of removing burrs from the grinders.

An assessment was made of the workers' perception of the both in manual molding and in finishing, using a two-part questionnaire: general perception of mental and physical fatigue (part 1) and the perception of discomfort or pain on a body map divided into 28 parts (part 2).

In part 1 some general data were collected such as age, height, weight shift, length of service in the company and in the sector. Another two questions were added regarding physical and mental fatigue, using a continuous scale of 150 mm with two anchors at the ends ("none" and "a lot"). The part 2 on the perception of pain and (or) discomfort uses a continuous scale of 90 mm with two anchors at the ends ("none" and "a lot"). The responses consisted of marking the workers in visual scales, which enabled data on their perceptions to be collected continuously, since marking could be made at any point of the scale. These continuous data were used for statistical analysis. This form of collection was based on the paper by Werner, Lindem and Ribeiro (2003).

4.2.1 Subjective Analysis of Exertion

The group analyzed consisted of 27 workers, of whom 15 were in the manual molding sector and 12 in the finishing sector and this is the total number of staff in these sectors. The averages for the general data of the group are 32.8 years old, 1.74 m tall and weigh 75.7 kg, the standard deviations being 9.5 years, 0.08 m and 12.6 kg. The general perception of physical and mental fatigue is shown in Figure 1, which clearly shows that the activities make large physical demands.

The initial analysis of perception of discomfort and (or) pain was made of the two sectors together, as shown in Figure 2. In this Figure (and in Figs 3, 4 and 5), besides the average values, what is shown is the LSD (Least Significant Differences Intervals) visualizing the significance of the F test.

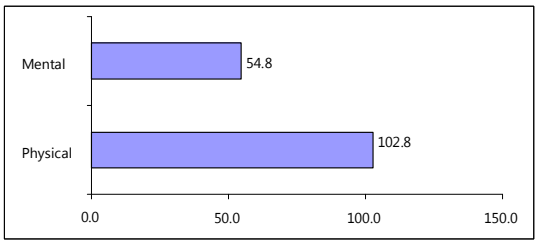

Figure 1: General perception of physical and mental fatigue in manual molding and finishing. Source: authors

The variance analysis (ANOVA) revealed at the 5% level of significance that there are differences in the discomfort and (or) pain perceived. The back, legs and arms are the parts of the body that presented the highest rates, and form a homogeneous group, i.e., they do not differ from each other in intensity. The second group consisting of the hips, feet, hands and neck are also homogeneous and comes next. The homogeneity of the two groups was also verified by variance analysis (ANOVA) at a 5% significance level.

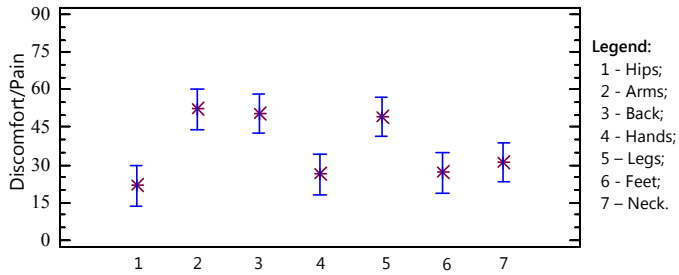

Figure 2: Perception of discomfort and (or) pain in manual molding with finishing. Source: authors

The same analysis was carried out separately for the sectors and the result is shown in Figures 3 and 4. For the manual molding sector (Figure 3), the variance analysis (ANOVA) revealed at the 5% level of significance that there are differences in the perception of discomfort and (or) pain. The back, legs and arms are the parts of the body parts that had the highest rates and form a homogeneous group, i.e., they do not differ from each other in intensity. The second group consists of the feet, hands and neck, which are also homogeneous, comes next. The homogeneity of the two groups was also verified by the variance analysis (ANOVA) at a 5% significance level. The statistical analysis showed that the hops could belong to either of the two groups.

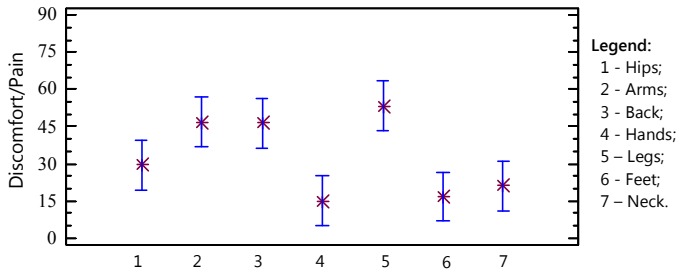

Figure 3: Perception of discomfort and (or) pain in the manual molding sector. Source: authors

For the finishing sector (Figure 4), the variance analysis (ANOVA) revealed that at a level of significance of 5% there are differences in the perception of discomfort and (or) pain only as regards the hips, where the perception of discomfort and (or) pain is at a lower level.

Figure 5 shows a comparison of the times that employees have been working in the sectors of manual molding and finishing. The average values were respectively 49.4 months and 14.8 months with standard deviations of 47.8 months and 18.3 months.

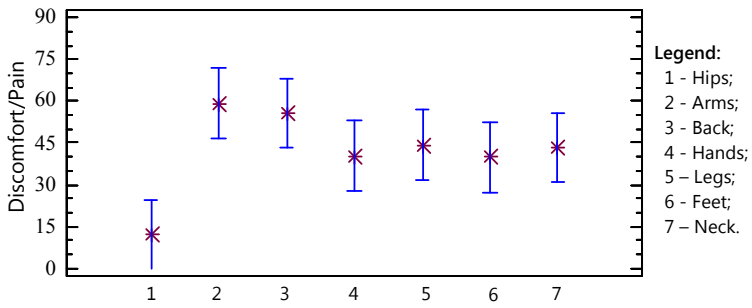

Figure 4: Perception of discomfort and (or) pain in the finishing sector. Source: authors

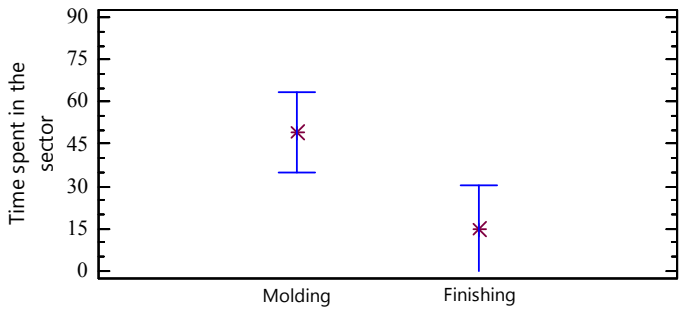

Figure 5: Time during which the employees have been working in the sectors (in months). Source: authors

On analyzing Figures 3 and 4 it is seen that the finishing sector, in its present state, is more critical than the manual molding sector. The perception of discomfort and (or) pain in this sector presented higher levels and in virtually all parts of the body. The time spent in the sector, shown in Figure 5, confirms this claim because there is a statistical difference at a significance level of 5% which suggests a higher turnover in this sector.

4.2.2 Physiological Evaluation of the Exertion

The physiological assessment of exertion was the main tool of thermography analysis, the focus of this work, which explored the potential of this technique in Ergonomics. The conclusions obtained from the thermography have aspects that are still controversial when it is a question of measuring human beings' skin temperature. These aspects are linked to the ongoing and complex mechanism of thermoregulation of the organism and the influence of the environmental conditions on the thermograms collected.

The equipment used for obtaining thermograms is a FLIR portable device, model InfraCam^{tm}. The equipment adequately met the requirements for analyzing human thermograms. Thermograms were collected from a volunteer in the finishing sector, which is considered the most critical one, who works at one of the grinders. It should be noted that we chose the sample size of one unit. This decision was made because of difficulties to remove the employees of the jobs. The tasks had to be interrupted to allow the collection of thermograms. The collection method is described below:

- Each collection consisted of acquiring thermal images of the arms (wrists to shoulders) and hands
- The reference measures (baselines) were collected at the beginning of the working day. The internal baseline was acquired in an air-conditioned environment in which the temperature and humidity were controlled as per Selfe *et al.* (2006). The external baseline was collected in the workplace
- The other measurements were taken after approximately 1.5 hours of activity and also in two ways, namely internally and externally as described above
- The measurements of the arms were taken at a distance of two meters and of one meter from the hands

The collection method was based on the thermograms for medical use in the collections in an air conditioned environment (internal baseline). Taking measurements in the workplace was an option for the researchers in order to investigate the validity of such measurements. Although there are restrictions to

this practice, the need for air-conditioned environments may be a factor limiting the use of the technique. The company in question has a laboratory for metallographic analysis, which is air conditioned, which facilitated the work. The option of collecting thermograms from the arms and hands was made for reasons of practicality. Taking Figure 4 into consideration, it is clear that these parts are at the same level of discomfort and (or) pain as the others (except the hip). Figure 6 presents the analysis regions of arms and hands in which the criterion of collection was that of the maximum value of each region. The three thermograms presented are from the internal baseline.

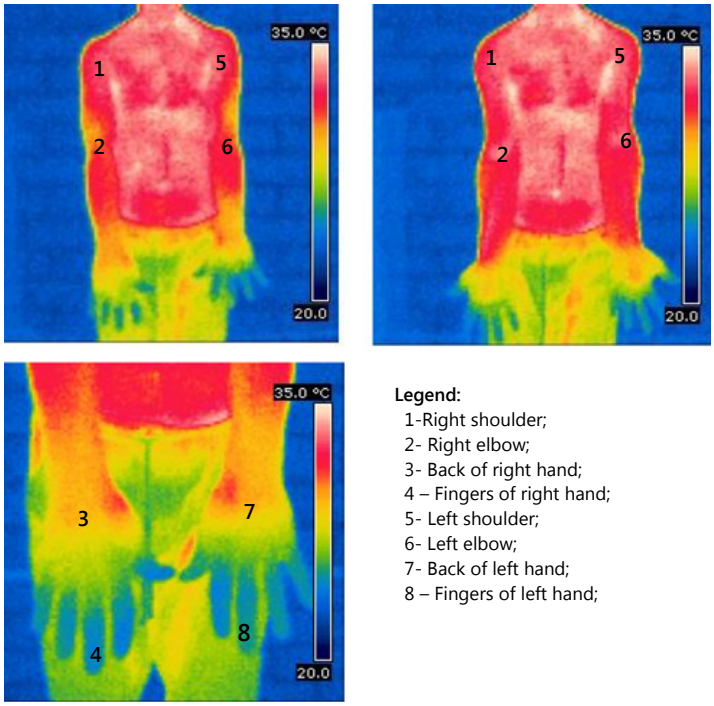

Figure 6: Analysis regions of the thermograms. Source: authors

The statistical analysis was performed with two factors (MANOVA). Condition of physical activity was one of the factors (at rest and working) and regions of the arms was the second factor. The response analyzed is the maximum skin temperature of the regions analyzed of the arms and hands. The variance analysis (MANOVA) showed at the 5% level of significance that there is an influence of the condition (at rest or working) and between the regions analyzed, as shown in Figures 7 and 8. In these same figures, besides the average values, the LSD (Least Significant Differences) intervals appear which assist in visualizing the significance of the F test.

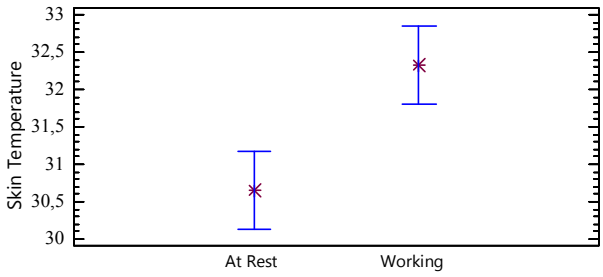

Figure 7: Skin temperature before and after 1.5 hours of activity. Source: authors

Figure 7 clearly shows the increase of the average skin temperature of the regions analyzed before and after 1.5 hours of activity. The average difference is 1.8 °C. A question to be interpreted is how much this difference represents in terms of physical exertion. For this case, it is understood that the difference represents great exertion demanded from the employee, because of the following arguments:

- An analysis of perceived pain and discomfort from the finishing sector (Figure 4) shows that the regions analyzed are in great demand

- The article by Guimarães, Fischer and Bittencourt (2004) made an analysis of an activity that requires great physical exertion and the biggest difference presented was 1.4 °C, before and after the activity

When questioned, the volunteer said that during the 1.5 hour activity only small parts had been worked on the emery grinding stones. Therefore the situation tends to be worse when heavier and larger parts are handled, and besides their being heavy, the parts are difficult to handle. Figure 8 shows the symmetry between the regions of the body, which was expected. It also shows a trend for the temperature to decrease from the shoulders to the extremities of the hands.

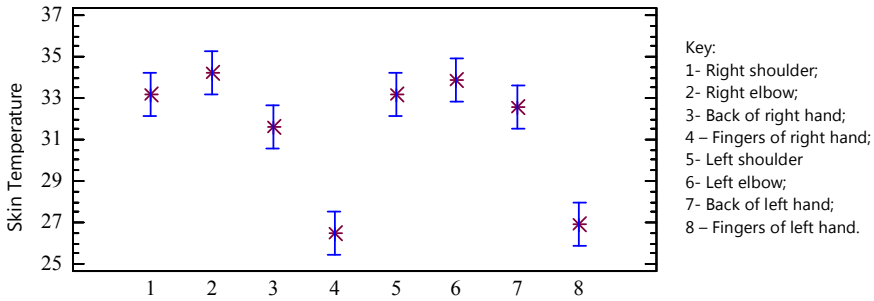

Figure 8: Skin temperature and the regions analysed. Source: authors

4.3 Proposals for Improvements in the Sectors Studied

The ergonomic analysis should be directed to the improvement in working environments. In this sense for the manual molding sector, the suggestions for improvements are as follows:

- Rotation: The rotation schedule of activities adopted by the company has brought about advances, but can still be enhanced. The rotation is still informal
- Weight of the molds and parts: some molds and parts are very heavy. It is suggested that the molds in the sector should be redistributed. New operational standards for molding operations should be drawn up with the prediction of the molds using the existing overhead crane
- Posture: all molds are on the ground and workers need to be bent over in many of the jobs. It is suggested that alternatives be sought that enable the elevation of the work area

For the finishing sector, the suggestions for improvements are as follows:

- Rotation: there is no rotation. The finishing operations are done in static positions and with repetitive movements. The high turnover of the sector reinforces this work as being the most critical in the company. It is suggested that a rotation system for these activities should be drawn up and implemented
- Jet of sand: it is suggested that this machine should have an acoustic enclosure or be removed to the external environment Posture: all molds are on the ground and workers need to be bent over in many of the jobs. It is suggested that alternatives be sought that enable the elevation of the work area
- To study a form of support and (or) bench that may facilitate the handling of parts and reduce the exertion against the grindstone
- Very large and heavy parts, these parts are deburred on the ground with hand sanders. Work benches (tables) can be planned so that the posture for this activity may decrease back pains

5 Conclusions

The sectors studied may have improved their working conditions with relatively simple actions that do not require many resources. The survey had a character that investigated the potentialities of thermography as a tool for analysis of physical exertion in energy sapping, such as a non-automated foundry. The results shown by the thermograms collected were consistent with the subjective analysis of discomfort and (or)

pain made in the sectors of molding and finishing. The cost of infrared cameras has been gradually reducing. However, technical issues of how to run trials on humans and how to analyze the results still hinder the proliferation of this technique in ergonomic analysis. We tried to help with this work has sought to make a contribution in this direction.

Future work in this area can be undertaken made to study trialling methods and collections of thermograms that target ergonomics. In sequence, reference values should be sought to assist in the analysis of thermograms before, during and after the physical activities demanded in work tasks.

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