Acta Scientific NUTRITIONAL HEALTH (ISSN:2582-1423)

Volume 6 Issue 12 December 2022

Research Article

Physiological Workload of Obese Chilean Miners Working at Altitudes between 3900 and 4200 Meters above Sea Level

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DOI: 10.31080/ASNH.2022.06.1153

Received: October 03, 2022

Published: November 11, 2022

Abstract

Mining work in mountainous regions is frequently carried out at altitudes between 3,000 and 5,000 meters above sea level and even higher. Nowadays, there is consensus that subjects, performing identical dynamic physical activities, achieve lower performances at high altitude than at sea level, with equal or greater physical strain. This can be risky for people with chronic diseases, especially respiratory, circulatory, and metabolic conditions. Consequently, the main objective of this study was to evaluate the heart rate in situ of obese workers, who carried out their activities in a mining company, whose tasks are located in a range between 3,700 and 4,200 meters above sea level.

The study was performed in 20 male miners, who carry out different jobs. The sampling was for convenience since the workers were chosen from a group whose body mass index exceeded a value of 30. All of them had medical pass to work at altitude. Follow-ups were done continuously during one shift per miner. Heart rate was measured with POLAR® monitors, simultaneously with time studies. Results showed that 80% of workers under the age of 45 did not exceed recommended limits of physiological load, while in those over 45, 80% reached higher average heart rates than recommended. It was also found that miners were exposed to high peak loads, which in extreme cases exceeded 140 heartbeats per minute. There was a significant correlation between the average heart rate and the peak of heartbeats. A more detailed analysis of two subjects with obesity class II, one with a sedentary job as operator of a frontal end loader and the other carrying out field activities as surveyor assistant, showed statistically significant differences in the physiological response to work.

It is concluded that depending on the type of activity, working at high altitude, may excessively overload the cardiovascular system. Therefore, the prescription of exercise and diet has to be under control of specialists and, in this sense, ergonomics can provide very useful information to understand the impact of work. The approach proposed in this study is laborious, but these miners face daily high-risk tasks carried out in extreme environmental conditions that cannot be modified. Therefore, knowledge of the physiological response, even with basic indicators such as heart rate, is important in ergonomic studies at high altitude, because may help to improve the organization of work to avoid dangerous peak loads.

Keywords: Obesity; Overweight; Heart Rate; Miners; High Altitud

Citation: Esteban Oñate*., et al.* "Physiological Workload of Obese Chilean Miners Working at Altitudes between 3900 and 4200 Meters above Sea Level". *Acta Scientific Nutritional Health* 6.12 (2022): 53-62.

Abbreviations

MASL: Meters Above Sea Level; VO_2: Oxygen Consumption; HR: Heart Rate; NEC: National Ergonomic Commission; HRT: Heart Rate Threshold; BMI: Body Mass Index

Introduction

From an ergonomic point of view, in mountainous regions some jobs are carried out under extreme conditions. A particular case is mining work performed at high altitude that, in some cases, exceed 5000 meters above sea level (MASL). Historically, there has been interest in the study of human adaptation to high altitude in native populations and also in subjects with acute exposure, in which adaptive changes have been evaluated in limited periods of different duration [1]. In the workplace, there are still many unknowns about chronic intermittent exposure, due to the variety of day and night shifts, the days that they remain in the mountains, and the number of working hours, varying from 8 to 12 daily. Furthermore, the altitude at which the miners do their jobs, can vary considerably, even over the course of a day [2].

It is now known that as altitude increases above sea level, the partial pressure of oxygen decreases. This brings about a reduction in the diffusion of oxygen to the tissues or hypoxia, which is the cause of the functional alterations that occur with brief or prolonged exposure to altitude [3]. From an ergonomic point of view, it is necessary to consider that hypoxia causes a decrease in working capacity. The reason for this fact is that the aerobic capacity (VO_2 max) decreases proportionally to the reduction of the partial pressure of oxygen in the inspired air. This trend has been corroborated in various studies [4-6]. In any case, care should be taken with average figures since, as Parker [7] highlights, the magnitude of the reduction in VO_2 max. has significant variability between subjects, partly determined by the conditions and protocols in which the comparisons were made. Nevertheless, there is consensus that subjects, performing identical dynamic physical activities, achieve lower performances at high altitude than at sea level, with equal or greater physical strain. This can be risky for people with chronic diseases, especially respiratory, circulatory, and metabolic conditions.

Studies on the human response during actual work are laborious and require the collaboration of workers. The two techniques commonly used to measure the physiological response during real work are oxygen consumption (VO_2) and heart rate (HR). Although VO_2 is a good indicator of the energy expenditure of an activity, it requires subjects to work breathing through respiratory masks. This is not well accepted by most workers and therefore is a limitation for routine evaluations. On the other hand, the HR, measured during work, is a very good indicator of cardiovascular effort, since the technique is not invasive and full days can be monitored without altering the activities. This technique, combined with time studies, allows to have a complete view of the duration and overload imposed by each task carried out by a worker [8].

One of the main problems at high altitude is to establish effort limits, since the criteria that are applied at sea level cannot be used directly at altitude. In Chile, there is a law for heavy work which benefit workers with one- or two-years early retirement for every five years if the work is qualified as heavy by the so-called National Ergonomic Commission (NEC). The law considers physical, mental, environmental and organizational aspects, according to criteria published in a guiding document [9]. It should be noted that all work at extreme altitudes should be considered heavy, because a series of physical, environmental and organizational factors are combined, such as shift work, life in camps away from the family or the long distances they travel daily when they sleep in their homes. For this reason, from the point of view of ergonomics, all efforts should be made to introduce improvements that help workers end the day without fatigue if the aim is to improve their quality of working life [10].

Returning to physiological overload, NEC guidelines establish that "*if the load, on average, does not exceed 40% of VO_2 max, it is presumed that the subject can complete his workday without fatigue*" [9]. They also highlight that "*due to the great inter individual variability observed in terms of the limitation of maximum oxygen consumption in hypobaric conditions, this guide does not establish artificial limits of geographic altitude to evaluate the effects of hypobaric hypoxia on workload.*" This statement, although evasive, only demonstrates the need to continue investigating this complex subject.

As mentioned before, VO_2 max. decreases at high altitudes, even in acclimatized subjects. A decrease in maximum heart rate has also been described, but studies show a high variability and most have been done with small samples [11]. On the other hand, tests such as lactate threshold, to determine the aerobic-anaerobic transition, are invasive and there are inconclusive results since, although blood lactate would be expected to increase in hypoxic condition, some researchers have shown the opposite [12]. This is known as the lactic acid paradox, which has led to a long controversy that is not shared by other specialists such as Jiménez., *et al.* [13]. and Van Hall., *et al.* [14]. However, as Bartlett and Lehnhard [15] highlight, this issue is not solved and could be explained by the different conditions in which the studies have been carried out. More feasible alternatives, such as heart rate threshold (HRT), have been discussed by Myers., *et al.* [16]. These authors place the HRT at 96 beats per minute, below the 115 beats per minute proposed for sea level for young people [17]. Although the reduction is completely justified, the limit of 96 beats was determined in a small sample of eight people of both sexes, regardless of age. These are limitations to define a reference for prolonged work under chronic intermittent exposure [18]. While many of these unknowns will take time to be solved, there is urgency to avoid that work activities at altitude expose workers to excessive loads, particularly people with cardiovascular risk factors. There is no doubt that the greatest risk occur when workers reach peak heart rates, a term that will be used to differentiate it from maximum heart rate. From an ergonomic perspective, it is necessary to intervene these tasks to avoid excess physiological load and reduce the risks for exposed workers.

In addition to the problems of working at altitude, the poor physical condition of workers and their trend to obesity can also increase the risk of fatigue. In fact, Pedreros., *et al.* [19], in a study of miners who worked at a median altitude of 2,500 meters above sea level, show a high prevalence of malnutrition, excess adipose tissue and altered anthropometric indicators. They also report an increase in cardiovascular risk factors above the average for the Chilean population. They highlight the importance of expanding the approach for assessing nutritional status and cardiovascular risk, both in mining workers and non-miners exposed to high altitude. Other study carried out by Apud and Meyer [8], examined the body composition in a sample of 220 miners who were working above 4,000 masl. They found that 32% had between 20 and 25% body fat, but even more critical is that 53% of the sample had more than 25% body fat. From an ergonomic and physiological point of view, these findings are very important for the study of work at altitude, since there is little information about the way in which obese workers are coping with the demands of their daily work under extreme conditions.

Consequently, the main objective of this study was to analyse the cardiovascular response in situ of obese workers, who carried out their activities in a mining company, whose tasks are located in a range between 3,700 and 4,200 MASL. The specific objectives were

- Determine the average and peak heart rate reached by workers at altitude.
- To analyse two individual cases, to demonstrate the usefulness of the combination of time and heart rate studies for the identification of tasks that generate high peaks for the cardiovascular system.
- Demonstrate the contribution that HR monitoring during the day can make to specialists in nutrition and physical education to guide actions according to objective information of physiological overload in obese workers.

Material and Methods

A total of 20 male miners, who worked in different jobs, were evaluated. The sampling was for convenience since the workers were chosen from a sample whose body mass index (BMI) exceeded a value of 30. All of them were more than six months old in the company and had a medical pass to work at altitude.

The workers carried out different activities. Seven of them performed administrative tasks or were machine operators, with sporadic displacements, while the remaining thirteen carried out activities in the field with frequent displacements combined with manual tasks of different intensity, such as mechanical or electrical maintenance.

Follow-ups were done continuously during one shift per miner. The purpose of the study was explained to each worker and prior to the field evaluation, their age, stature and body mass were recorded with a clinical scale Detecto®. With these last two variables, the BMI (body mass index) was calculated, dividing the kilograms of body mass by stature expressed in meters squared. Their body fat percentage was also recorded by impedanciometry, using an OMRON® HBF-306INT field kit.

Heart rate was measured with POLAR® monitors, simultaneously with time studies using a technique proposed by the ILO [20]. For these purposes, the work is divided into principal activities, which are those directly required to do the task and secondary activities, which are those that contribute indirectly to the fulfilment of the main activity. Waits and breaks are also recorded. To carry out the time study, the chronometer starts at the beginning of the first activity and does not stop until the study is completed. At the end of each activity, the time is recorded from the stopwatch, and the second activity continues to be measured, and so on, without stopping the stopwatch. Finally, the times of each activity are obtained by successive subtractions from the recorded times. This procedure ensures the recording of all the time that the worker is under observation.

Field evaluations were carried out on the third or fourth day of exposure. Most of the workers had 7 x 7 or 4 x 3 shifts and the evaluations were made only during the day. For the analysis of the information, the software Statistica® version 12 was used.

Results and Discussion

Table 1 shows the physical characteristics of the miners.

Variables	n	Mean	Minimum	Maximum	Std. Dev.
Age (years)	20	43,9	28	58	9,23
Stature (cm)	20	174,2	166,6	183,0	5,20
Body mass (kg)	20	103,7	95,5	126,1	8,04
Fat mass (%)	20	30,8	26,6	36,8	2,63
Fat mass (kg)	20	32,1	25,4	46,4	4,98
Body mass index (BMI)	20	34,3	30,0	39,6	2,78
Waist circumference (cm)	20	113,7	103,0	125,5	7,61

Table 1: Age and characteristics of size and body composition of the 20 workers evaluated.

As can be seen in table 1, all the indicators confirm that the workers were obese to different degrees. Considering that in Chile, the "Technical Guide for Exposure to Chronic Intermittent Hypobaric Hypoxia" of the Ministry of Health establishes a maximum BMI of 35, it is interesting to analyse the distribution of this indicator in the sample studied, which can be seen in the figure 1.

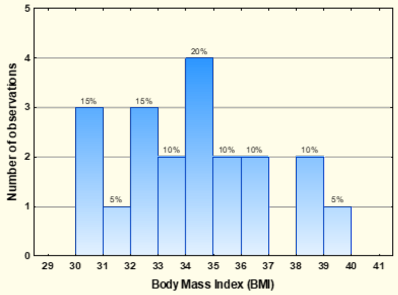

Figure 1: Distribution of body mass index (BMI).

Considering the classification of the WHO [21], subjects with a BMI over 30 qualify as obesity class I and over 35 reach a level of obesity class II. As can be seen in the figure, 35% of the workers evaluated carry obesity class II, which exceeds the level recommended by the Ministry of Health. This should be taken into account when making recommendations for workers performing activities in critical environments. In fact, by accepting miners with a BMI over 30, they are validating that obese people, since they start their work in high-altitude, are exposed to risky tasks due to their poor physical condition. It should be noted that for this discussion the BMI was taken, as it is the index recommended by the Chilean Ministry of Health, but it is pertinent to note that there was a significant correlation between BMI and the weight of fat mass (r = 0.84) and also with the waist circumference (r = 0.78), which only confirms the obesity of these workers.

Variable	Mean	Minimum	Maximum	Std. Dev.
Work in the company (years)	16,3	1,1	34,0	10,58
Evaluation (minutes per miner)	400,9	207,0	626,0	105,53
Principal times (%)	61,8	7,7	91,6	23,30
Secondary times (%)	22,1	1,5	52,8	16,27
Rest pauses (%)	13,9	0,0	54,6	13,11

Table 2: Years working for the company and results of the time study (n = 20).

With regard to the work itself, table 2 shows the result of the time study. It also includes the number of years that the 20 miners work for the company. As can be seen, the range is quite wide since it fluctuates between 1.1 and 34 years. It is striking to see in table 2, the wide variation that exists in dedication to main activities, secondary times and breaks. Regarding breaks, the average for 400.9 minutes of observation was 55.6 minutes. However, the range shows that there are workers who do not take formal breaks, while some of them rest more than 50% of the day, which could be associated with tasks with high physical demands that, by their nature, make workers rest to recover, a topic that will be discussed later in this paper.

Table 3 shows the average, minimum and peak values for the heart rate recorded during 20 days in each evaluated worker.

HR at work	Mean	Minimum	Maximum	Std. Dev.
Average	88,4	71,8	120,9	11,82
Lower value	69,6	57,0	89,0	9,26
Peak	124,3	101,0	166,0	17,04

Table 3: Heart rate (HR) expressed in beats per minute as average of 20 days of evaluation at work.

To analyse the results summarized in table 3, it is necessary to consider the age of each worker, which ranged from 28 to 58 years. In this sense, Apud and Oñate [22] propose a reduction in the average physiological load per day, based on Table 4, modified from Apud., *et al*. [17]. Table 4 summarizes the proposed values for sea level and the suggested limits for altitudes between 3,800 and 4,200 meters above sea level, for different age groups. The reduction is based mainly on Mourot's [11] research that compiled 85 studies on the subject, presenting equations to predict the decrease in maximum heart rate according to age and altitude. As this researcher points out, there is a lot of dispersion, but in general the reduction in the maximum heart rate oscillates on average between 7 and 16 beats per minute at altitudes of 4,000 MASL [11]. This is coincident with information from Apud and Oñate [22]. who evaluated the increase in heart rate at sea level and at 4,000 MASL during submaximal exercises on a bicycle ergometer. In both cases, the linear relationship between heart rate and load expressed in Watts was practically parallel. They found that HR was significantly higher for equal workload at high altitude, very much within the range described by other researchers but with the same limitation which was the small size of the sample. For that reason, the HR limits included in table 4 consider the information from Mourot [11]. It should be noted that the values reported in table 4 are average for a shift resulting from the combination of light activities, heavy work and breaks.

Age range	HR sea level	HR altitude
20-24	115	99
25-29	112	96
30-34	110	94
35-39	108	92
40-44	106	90
45-49	104	88
50-54	102	86
55-59	100	84

Table 4: Suggested average heart rate limits (beats per minute) for a working day at sea level and at altitudes ranging from 3,800 to 4,200 masl for subjects of different ages.

According to the values presented in table 4, 80% of workers under the age of 45 did not exceed recommended limits of physiological load, while in those over 45, 80% reached higher average heart rates than recommended. Although the limits indicated in Table 4 should be taken with caution, since more research is required, what is absolutely true is that the work sometimes subjects miners to high peak loads, which in extreme cases exceed 140 heartbeats per minute; that have an impact on the increase of the average heart rate of the workday, as illustrated in figure 2. The correlation coefficient r = 0.81 indicates a statistically significant association between the average heart rate and the peak of heartbeats. This may seem obvious, but it is important to identify the loads that increase the average and that may be fatiguing for workers. There is no doubt that ergonomic work should start seeking alternatives to reduce the peak loads.

Figure 2: Relationship between average and peak heart rate.

In Ergonomics, the case-by-case study, with observations in situ, is essential to adapt work to men and women who carry it out. However, such an analysis would be too extensive for a publication of this nature. For this reason, since it is impossible to go into detail for each of the 20 jobs studied, two cases will be analysed to demonstrate the usefulness of heart rate monitoring associated with time studies in extreme conditions. As will be seen, this combination of techniques allows to detect and explain the factors that generate physiological overload and to guide the measures that can be taken to reduce it.

The workers were an assistant for the surveyor, and a front-end loader operator. The surveyor's assistant carried out rock marking tasks, in addition to loading and placing stakes. All his tasks were done walking outdoors. He worked a 9x3 shift, that is, nine days of work for three days off. On the other hand, the front loader operator, worked sitting in a cabin from where he loaded trains with mineral and exceptionally also loaded ore in trucks. He worked a 4-day shift on site and 4 days off. Both workers had mining experience, and both were obese class II, with a BMI greater than 35 and with high levels of body fat.

Table 5 shows their physical characteristics and their response to work.

Age range	HR sea level	HR altitude
20-24	115	99
25-29	112	96
30-34	110	94
35-39	108	92
40-44	106	90
45-49	104	88
50-54	102	86
55-59	100	84

Table 4: Suggested average heart rate limits (beats per minute) for a working day at sea level and at altitudes ranging from 3,800 to 4,200 masl for subjects of different ages.

The first thing that stands out in table 5 is the difference in the distribution of working times. As can be seen, the front loader operator dedicated 67.7% of the time to the main activities, with few secondary activities and 31.9% breaks. In contrast, the surveyor assistant worked only 33.8% in the main activities, with less break time and more than half of the day in secondary activities, mainly determined because he had to walk to different places. There are also clear differences in heart rate; while the front loader operator has an average of 71.8 beats per minute, which is within the acceptable range for his age, the surveyor assistant averages 105.8 beats per minute that would be heavy even at sea level. The statistical analysis presented in table 6, indicates that the differences between mean heart rate in both workers were highly significant.

Surveyor assistant Mean (n = 309)	Front end loader operator Mean (n = 626)	T-value	df	p
105,8	71,8	52,38	933	0,00

Table 6: Statistical comparison of heart rate of the surveyor assistant and the operator of front-end loader: t-test for independent samples.

It is important to keep in mind that the surveyor assistant peak load was 161 beats per minute, which for the altitude condition is very close to the maximum heart rate for this 49 years old worker, which is certainly strenuous. For this reason, it is important to analyse the distribution of loads, in relation to the activities they carry out. Tables 7 and 8 show a synthesis of the results of the time studies, while Figure 3 includes the heart rate monitoring for the two workers.

Start	Activity	End	Duration minutes	% of the shift
8:01	Prepare equipment to go to the mine	8:35	34	11,14
8:35	Van Travel	9:10	35	11,47
9:10	Walk in the mine marking and placing stakes	9:42	32	10,49
9:42	Pause	10:12	30	9,8
10:12	Van Travel	10:42	30	9,8
10:42	Continue working main activities	11:33	51	16,72
11:33	Pause	11:44	11	3,6
11:44	Continue working main activities	11:54	10	3,3
11:54	Van Travel	12:25	31	10,1
12:25	Continue working in main activities	12:35	10	3,3
12:35	Van Travel	13:06	31	10,1
	Total		305	100

Table 7: Time study for the surveyor assistant.

Start	Activity	End	Duration minutes	% of the shift
7:40	Load de train with copper mineral	8:53	73	11,76
8:53	Talk to his supervisor	8:59	06	0,97
8:59	Wait for material	9:24	25	4,03
9:24	Start loading train	10:53	89	14,33
10:53	Continue loading	11:30	37	5,96
11:30	He walk to the dressing room	11:40	10	1,61
11:40	Lunch	13:00	80	12,88
13:00	Talk to his supervisor	13:20	20	3,22
13:20	Continue loading	14:58	98	15,78
14:58	Check the train line	15:05	07	1,13
15:05	He walk to solve the problem with the line	15:20	15	2,42
15:20	Meeting with his supervisor	16:12	52	8,37
16:12	Wait for the train arrival	17:45	93	14,98
17:45	Continue loading	18:01	16	2,58
	Total		621	100

Table 8: Time study for the operator of front-end loader.

Figure 3 shows the heart rate in relation to the time of the day. It can be seen that the surveyor assistant (A) starts his work with high HR. The time study, summarized in table 7, revealed that, in that instance, he was preparing materials to go out in the field, failing to recover when he drives a van for 35 minutes. From then on, some peak loads are observed, coinciding with his work that requires him to walk on terrain with slopes and obstacles. The highest peak, 161 heartbeats per minute, occurs at 11:47, when taking measurements walking in the field. The red line in figure 3A highlights the recommended average heart rate limit, which, as observed, is exceeded for almost the entire day. In contrast, as seen in Figure 3B, the front loader operator's job is exactly the opposite. It can be seen that most of the records are below the red line, which marks the acceptable limit for the average of the day. Looking closely at Figure 3B, some peaks are detected. The first one, of 101 beats per minute, occurs at 11:28 am when he was walking to lunch, as shown in table 8. Then, between 15:05 and 15:20, when he gets off the machine to observe a malfunction, it reaches the highest peak of 118 beats per minute. Finally, the third peak is observed at 6:00 p.m., when the day ends and he gets off the machine.

Figure 3: Distribution of heart rate throughout the day by a surveyor assistant (A) and a front-end loader operator (B).

Although both workers share a health problem that is their obesity, the nature of their activities indicates that there is no single recipe to tackle the problem that afflicts them and that the impact of work on both is completely different. In the case of the front loader operator, he has sufficient breaks and is inserted in a process that takes place from inside the cabin of a machine. It is no surprise that if he is sitting for long periods, when he gets off the machine and walks short distances, his heart rate increases. Without a doubt, this can also affect many of his daily activities when he displaces his body mass. In contrast, the surveyor assistant is exposed to high overload throughout his workday. All his work is carried out in the open air, in mountainous and rugged areas, at altitudes between 4,000 and 4,200 meters above sea level, as shown in figure 4.

Figure 4: Places where the surveyor assistant walks sampling.

As can be seen in figure 4, the places are uneven, with steep slopes. From an ergonomic point of view one solution would be to search mechanical help, but it is a difficult task due to the cost and the complex access in the mountains. In work under extreme conditions, the protection also involves motivating these workers to participate in physical rehabilitation programs, with medical control, guided by specialists in nutrition and physical activity. It must be considered that an obese person, by the mere fact of moving his body mass in areas such as those illustrated, even if he does nothing more than walk slowly, can have very high energy expenditure, which overload his respiratory, cardiovascular and metabolic systems. This is reflected in high heart rates, which can be a risk for anyone who does not have a good physical fitness, but particularly for obese workers or miners with other metabolic, cardiovascular or respiratory health problems.

When critical obesity levels are present and people work long hours, the solution involves integrated work between health professionals and ergonomists or work physiologists. In fact, the "Technical Guide on Occupational Exposure to Chronic Intermittent Hypobaric Hypoxia at High Altitude" from the Chilean Ministry of Health [23] indicates that jobs with a high physical and ergonomic load must be identified, with their corresponding risk analysis and risk mitigation and control plans. The prescription of exercise and diet has to be authorized by specialists and, in this sense, ergonomics can provide very useful information to understand the impact of work. Having shown the result of two obese miners, whose jobs have such different physical demands, highlights that the prescription of exercise and food cannot be the same in both cases, if one walks a large part of the day and the other remains sitting almost all working time. The approach described is certainly laborious, but these miners face daily high-risk tasks carried out in extreme environmental conditions that cannot be modified.

Finally, one aspect that stems from this study is that in Chile the "Technical Guide on Occupational Exposure to Chronic Intermittent Hypobaric Hypoxia at High Altitude" [23] textually recommend *"Evaluation of Chronic Intermittent Hypobaric Surveillance: up to 3 years if younger than 40 years; up to 2 years if younger than 55 years or older than 40 years; and up to 1 year if older than 55 years"*. Undoubtedly, if a BMI below 35 is considered in the entry criteria, for those workers who are checked every two or three years and who enter with a BMI between 30 and 35, that is, already being obese, it is predictable, especially for those living in camps, eating in casinos and with few facilities for recreational and physical training, that the trend to obesity will continue increasing. Therefore, it is necessary to devote time to study work and workers on site and on this basis make ergonomic adjustments to reduce workload, but also try to integrate ergonomics in a joint effort of education and treatment together with medical teams and the support of nutritionists and physical educators.

Conclusions

The main objective of this study was to analyse the impact of working at high altitude on heart rate measured in situ, from a sample of 20 obese miners, who carried out their work at altitudes between 3,800 and 4,200 meters above sea level. The results allow the following conclusions

- Depending on the type of activity, working at high altitude, may excessively overload the cardiovascular system.
- In the case of obese workers over 45 years, 80% reached heart rate levels above what is recommended for a workday, while 20% of workers under 45 years of age exceeded the reference levels proposed in this study.
- Since obesity is only one of the elements of cardiovascular risk, future research should include information on other factors such as smoking habits, blood pressure, presence or absence of diabetes, and other metabolic, cardiovascular and respiratory conditions.

- It is concluded that more research is needed to define accurate physiological limits for work at high altitude, a complex issue, considering that the exposure is intermittent, that the work is carried out in a wide range of heights and with a great variety of shifts and daily work of different duration.
- It is also concluded that the lack of exact reference limits for the average heart rate are not a limitation to study the work under these extreme conditions and that the detailed case by case analysis may provide valuable information to protect workers.
- The study shows that the combination of time studies, with simultaneous and coordinated monitoring of heart rate, can guide the search for technological and organizational alternatives to reduce the physiological overload, such as reorganization of breaks, redistribution of activities and other technological measures that require specific studies.
- The proposed methodology can also be a contribution to what is established in the "Technical Guide on Occupational Exposure to Chronic Intermittent Hypobaric Hypoxia at High Altitude", where it is stated that *"workplaces with a high physical and ergonomic load must be identified, with its corresponding risk analysis and risk mitigation and control plans"*. Regarding the latter, there is no doubt that knowledge of the physiological response, even though basic indicators such as heart rate, is essential in ergonomic studies at geographic altitude.

Conflict of Interest

Authors claim no conflicts of interest.

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