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Physical work capacity and heart rate in construction workers

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Abstract. Physical workload emphasizes the psychophysical demands that an employee faces during his/her workday, being important to analyze those aspects that influence his or her performance when carrying out his/her duties at work. To calculate construction workers' physical workload and its influence on their health, evaluating functional adaptation to their work. 20 construction workers were analyzed, measuring their heart rate by means of a monitor with an optical sensor using Chamoux and Frimat's criteria for work demands, verifying the perception of physical load using the Borg scale. Based on Frimat's coefficient, a minimum of 7 and a maximum of 32 points were established, obtaining that 11 workers (55%) have an extremely demanding workload. According to Chamoux CCR: 7 workers (35%) had a hard cardiac cost, and 1 worker (5%) had a very hard cardiac cost. Borg scale determined that masonry, plastering, and foundry tasks are perceived as heavy work demand. In some studies, 75% of masons showed risk of physical overexertion and 50% showed a relative cardiac cost, according to the index. Likewise, other studies showed that stevedores had great exposure to this type of overexertion. Conclusions, Heart rate monitoring for determining physical workload is a reliable method and together with the Borg scale, they represent low-cost tools for health care.

Keywords: Work capacity, Heart rate, Workers, construction.

1 Introduction

Physical workload refers to the psychophysical demands to which every employee is exposed during their workday, and which calls for a study in the two areas, physical and mental demands, where impact is perceived in different proportions in all work activities. Indeed, during their workday, every worker is subjected to physical and mental demands that influence their metabolism, which can be observed through oxygen consumption and heart rate. Thus, it is necessary to estimate physical workload and relate it to workers' physiological response to the effort they make during their workday; considering as heavy, the work that accelerates physical or mental exertion, i.e., the one that exceeds the acceptable limits of the worker's capacity, causing premature aging even when no occupational disease is triggered [1].

It is important to note that calculation of the maximum exposure to physical work that an employee can perform in his/her working day without producing fatigue during a given period of time is the so-called maximum acceptable work time. [2]. Indeed, studies related to the subject have shown that reducing time of exposure to strenuous work, promoting healthy work/rest patterns, and taking short, consecutive breaks are activities that prevent the onset of work-related diseases. [3]

In this context, physiological responses are influenced by factors that are linked to the type of activity performed. For instance, it is static if it involves greater postural effort, and dynamic if it is associated with repetitive movements, use of force, and manual handling of loads. When the demand to make the effort reaches a level that exceeds the worker's capacity, considerable energy expenditure is produced, and fatigue is triggered. In order to perform an accurate diagnosis for the sake of this study, it is essential to comprehensively assess the worker while he/she is carrying out his/her duties. [4] [5] For this reason, to quantitatively assess physical workload, three methods were proposed, especially in the context of physical and muscular work:

a) Calculation of energy expenditure, or calories burned, during performance of work, estimating total consumption with previously standardized tables.
b) Assessment of heart rate during work using parameters for calculating energy expenditure and cardiovascular capacity in relation to oxygen O_2 consumption.
c) Keeping track of O_2 expired during work activity using devices that monitor the worker's expired air [6].

In this regard, in chapter 29 on Ergonomics in the International Labor Organization's Encyclopedia of occupational health and safety Smolander and Leohevaara, making reference to muscular work, mention that: acceptable physical workload can be estimated during heavy work using heart rate records, considering the values of maximum heart rate minus resting heart rate, the resulting value is regarded as the cardiovascular reserve. Likewise, energy consumption during work is calculated with the value of the average working heart rate minus resting heart rate. [6] [7]

Hence, it is essential to timely identify the symptoms of diseases associated with excessive workload or to determine if an employee is suffering from any condition that affects their physical well-being. Therefore, it is necessary to know which occupations or work activities are associated with greater physical effort in order to perform corrective actions and prevent the appearance of fatigue, exhaustion, or occupational diseases, allowing for a positive outcome on workers' effectiveness and productivity.

Indeed, studies based on monitoring oxygen consumption through biological parameters such as heart rate or heartbeat, which are reliable indicators of the level of oxygen consumption, allow an assessment of both cardiovascular effort and presence of physiological wear. In this sense, this parameter helps to determine if the worker shows an excess of physical workload through the level of work intensity, which must be in balance with cardiorespiratory functioning, and which is analyzed by means of vital signs that can be valued and that are of the utmost importance to determine if there is presence of physical overload in order to avoid inflammatory processes that would harm the worker's health and cause a reduction in productivity and quality of work. In this context, there are instruments that are used for heart rate monitoring:

- A heart rate monitor
- A Holter, which records cardiac activity continuously and on an outpatient basis through electrodes placed on the patient's thorax.

On the other hand, it should be noted that employees in the construction sector perform activities that could be potentially harmful to their physical safety if due precautions are not taken. It is important that these workers and their managers are aware of the risks to which they are exposed, especially the damage that these factors can cause to their health. [8]. As a matter of fact, the statistics published by the International Labor Organization (ILO) reveal that every year, globally, 317 million people have accidents at work, and 2.34 million people lose their lives due to work-related accidents and diseases. On the other hand, America is enduring important challenges in this matter since, consistent with the data available, there are 11.1 deaths per 100,000 workers in the industry sector, 10.7 in agriculture and 6.9 in the service sector. The key sectors of the regional economy such as mining, construction, agriculture, and fishing are also the sectors that yield the most accidents. In addition to the human cost of diseases and accidents, the impact they have on production and economic performance must be taken into account, as well as the considerable health costs they trigger [9].

The World Health Organization (WHO) and the ILO carried out an analysis of deaths caused by ischemic heart disease between the years 2000 and 2016 and it was inferred that long working hours increased the cases of death caused by ischemic heart disease by 42% and the deaths caused by cerebrovascular accident by 19%. 72% of the fatalities were 45-to-74-year-old men from the Western Pacific and South-East Asia regions who worked 55 hours or more per week, which indicates that one third of the total estimated morbidity and mortality is attributed to long working hours, a risk factor that contributes to the increase in work-related diseases. The study concluded that working 55 or more hours a week increases the risk of stroke by 35% and the risk of death caused by ischemic heart disease by 17% compared to a 35-40-hour shift per week. [10].

In this regard, Echeverri and Urquino identified risks in the construction workplace by examining safety conditions and demonstrated that work-related factors together with other non-occupational factors increase the risk of developing diseases. Occupational diseases are a direct result of an individual performing certain tasks at work. There must be a causal relationship between the work performed and the disease that causes the disability or death [11].

Currently, there are few studies on the application of ergonomics and work physiology to analyze processes and tasks related to the impacts on the well-being of employees in the construction sector. That is why the methods for estimating this type of energy consumption are also very scarce and almost non-existent, mainly because of the variety of individual tasks performed in the construction sector [12].

Based on the information presented above, assessment of construction workers for calculating the physical workload to which they are exposed in each of their positions is of great interest in order to keep track and monitor workers' health; since this analysis will allow for an assessment of the functional adaptation to their jobs in relation to the variety of tasks they perform through the heart rate monitoring system; emphasizing that, for such monitoring, cardiac indices will be used and, through the application of criteria, the degree of physical effort demanded by the task or job will be calculated based on an 8-hour-a-day job.

2 Methodology

The study was carried out at one of the housing development projects under construction located in the canton of Samborondon, in La Puntilla parish. Samborondon is part of the Guayas province and is located in the lower section of the Guayas River basin. It is separated from the city of Guayaquil by the Daule River and from the city of Duran by the Babahoyo River. Its climate is characterized by possessing two distinct seasons: a dry season and a rainy season, each lasting approximately six months. The temperatures are moderate, ranging between 30 and 32 degrees Celsius during the rainy season, and between 22 and 25 degrees Celsius during the dry season. The population chosen for the study was made up by 20 construction workers whose main responsibility was the construction of houses and whose multiple tasks included placing blocks, building exterior walls and partition walls that would later be covered with cement as well as building structures using prestressed concrete for the construction of slabs and beams, covering walls and ceilings with plastering material, as well as other construction works.

The study was carried out at the beginning of the working day. The conditions that the workers had to meet to be part of the study are indicated below:

- Minimum work time of 2 weeks.

- The work would not be part-time; their working day would consist of, at least, 4 hours a day.
- Not to have any heart or lung-related condition, including common respiratory diseases.
- During the assessment, the worker should have not drunk beverages that contain caffeine or alcohol.
- The worker must not have carried out demanding physical activity before the assessment.

It is worth mentioning that for the study, the Physical Activity Readiness Questionnaire test (PAR-Q test) was used before the physiological assessment. Subjects who had one or more positive answers were not eligible for the study. Before placing the heart rate monitor, a card was recorded with the following information:

- Height in centimeters.
- Body weight in kilograms.
- Blood pressure in mm Hg.
- Patient should take a ten-minute rest.
- Resting heart rate should be measured.

Next, the Borg Physical Effort Perception Scale was applied. For this study, a monitor with a bracelet-type optical heart rate sensor was used. It measured the heart rate in the arm or on the temple. The monitor is made up by 6 LEDs that shine light onto the surface of the person's skin, penetrating only a few millimeters, where the blood reflects it. Using this information from the reflected light, the monitor determines the speed of blood flow and, in consequence, the heart rate. The advantage to this method is the fact that it provides greater freedom of movement while recording heart rate during the working day. [13] [14].

The indicators for measuring heart rate are those suggested in the Technical Note on Prevention 295 by the National Institute for Safety and Health at Work from Spain; and the Chamoux [15] and Frimat [16]criteria were used for quantifying the demands of the task. Tables 1 and 2 show the information in detail.

The elements considered for the calculation of the various indicators in both methodologies are the following:

- **Maximum heart rate (Max HR).** It was calculated using the formula given by Tanaka et al. (208.7 – (0.73 x age in years).
- **Resting heart rate (RHR).** It was calculated by measuring the worker's heart rate after he had remained seated for at least 10 minutes. It was also necessary to record the 1st percentile out of the data recorded in the heart rate sensor.
- **Average heart rate while working (MHR).** It is shown in the optical heart rate sensor. It is the average rate obtained during a set period. The variable range is determined, which goes from the 5th percentile of slowest heart rate (Min HR) to the 95th percentile of Maximum Heart Rate (Max HR).
- **Maximum heart rate while working (Max HR).** Corresponds to the maximum value that the optical heart rate sensor provided during the recording time.

- **Absolute cardiac cost (ACC).** The variation between the average heart rate and the resting heart rate is known as differential heart rate. This differential heart rate offers the possibility of analyzing a worker's individual capacity before a specific task, i.e., it provides a notion of the active physical load associated with the job position.
- **Relative Cardiac Cost (RCC).** This operation makes it possible to assess and obtain an approximation of the worker's adaptation capacity to his/her job position:
  RCC= ACC/(Max HR while working-RHR).
- **Acceleration of heart rate (Δ HR).** The value is calculated by subtracting average heart rate from maximum heart rate while working.

Table 1. Chamoux criteria. Task demand is classified by calculating absolute and relative cardiac cost.

CHAMOUX CRITERIA			
Abosolute cardiac cost	**Job position absolute cost**	**Relative cardiac cost**	**Cardiac cost for individual**
0 - 9	Very light	0 - 9	Very light
10 - 19	Light	10 - 19	Light
20 - 29	A little moderate	20 - 29	Moderate
30 - 39	Moderate	30 - 39	Heavy
40 - 49	A little heavy	40 - 49	Very heavy
50 - 59	Heavy		
60 - 69	Intense		

Source: [17]

Table 2. Frimat's criteria. Physical load is classified using coefficient values and heart rate parameters.

FRIMAT'S TASK RANKING			
Score	**Cardiac demand**	**Score**	**Cardiac demand**
≥ 25 points	Extremely hard	15 -18 points	Bearable
23 - 24 points	Very hard	13 - 14 points	Light
21 - 22 points	Distressing	11 - 12 points	Very light
19 - 20 points	Bearable	≤ 10	Minimum workload

Source: [18]

Table 3. Assessment of the task – FRIMAT.

FRIMAT'S TASK RANKING			
Score	**Cardiac demand**	**Score**	**Cardiac demand**
≥ 25 points	Extremely hard	15 -18 points	Bearable
23 - 24 points	Very hard	13 - 14 points	Light
21 - 22 points	Distressing	11 - 12 points	Very light
19 - 20 points	Bearable	≤ 10	Minimum workload

For simpler reference values, the following classification can be used:

Table 4. Reference values table.

CARDIAC DEMAND	MHR	Δ HR
Distressing	> 110	> 30
Bearable	100 a110	20 a 30
Acceptable	< 100	< 20

3 Results and discussion

The characteristics of the population studied are shown in Table 5, where age, height, weight, Body Mass Index (BMI) and seniority in the job are described.

Table 5. Characteristics of workers in the construction sector.

Characteristics	Mean	Standard deviation	MAD	Interquartile Range (IQR)
Age (years)	33.9	8.9	31.5	11.25
Height	166.05	7.79	168	9.5
Weight (kg)	73.83	15.9	71	24
BMI (Kg/m²)	26.6	5	25	8.7
Seniority (months)	87.6	57.8	90	75

Regarding the variables of consumption of liquor and tobacco obtained from the 20 workers, only 1 worker had the habit of smoking one cigarette a day; however, he did not smoke prior to the hours of the study. Concerning the habit of drinking alcohol, 5 workers, which corresponds to 25% of the population under study, drink an average of 6.5 beers on weekends and a median of 6. Regarding the variable of sports playing and physical conditioning, out of the 20 workers, only 8 (40%) stated that they practice sports; 4 of them do it once a week (50%), 3 play sports twice a week (38%) and 1 does it once every two weeks (13%).

When analyzing the physiological variables; RHR was between 45 and 80 beats/min (mean: 64.5, SD: 9.25, interquartile range: 11.75). Mean HR was between 68 and 118 beats/min (median: 99, SD: 11.99, interquartile range: 10). Max HR was between 101 and 171 beats/min (median: 146, SD: 19.78, interquartile range: 30). Likewise, the Kilocalories consumed per hour were between 83.87 and 425.1 2 (median: 256.87, SD: 89.63, interquartile range: 122.31). Average metabolic load was 264,475 Kcal/h, which would be in the range of 200 to 350 Kcal/hour, corresponding to moderate work in accordance with Executive Decree 2393.

It should be noted that all the workers had an 8-hour day under climatic conditions described by the National Institute of Meteorology and Hydrology (INAMIH) as: temperature ranging from between 25 ºC and 32 ºC with humidity ranging between 80% and 92%.

Table 6. Qualitative results of the physical workload per worker and globally for construction worker positions obtained by extrapolating data to a full working day.

OCCUPATION	CHAMOUX CRITERIA				FRIMAT'S CRITERIA	
	ASSESSMENT OF THE POSITION		WORKER'S ASSESSMENT			
	ACC	Assessment	CCR	Assessment	Demand	Assessment
Builder	46	A little heavy	44.66	Very heavy	22	Extremely hard
Builder	32	Moderate	31.07	Heavy	28	Extremely hard
Builder	36	Moderate	29	Moderate	27	Extremely hard
Builder	26	A little moderate	20.9	Moderate	32	Extremely hard
Builder	37	Moderate	35.9	Heavy	28	Extremely hard
Builder	38	Moderate	30	Heavy	26	Extremely hard
Builder	39	Moderate	34.5	Heavy	26	Extremely hard
Builder	23	A little moderate	20.17	Moderate	15	Bearable
Builder	28	A little moderate	23.14	Moderate	14	Light
Builder	22	A little moderate	19	Light	20	Demanding
Builder-oficial	50	Heavy	35.46	Heavy	28	Extremely hard
Builder-oficial	25	A little moderate	24.5	Moderate	26	Extremely hard
Electrician	11	Light	10.67	Light	12	Very Light

Plumber	25	A little moderate	19.37	Light	19	Demanding
Plumber	25	A little moderate	22.72	Moderate	22	Hard
Cleaner -Finisher	13	Light	10.15	Light	7	Minimum workload
Painter	23	A little moderate	16.54	Light	16	Bearable
Painter	25	A little moderate	29.3	Moderate	22	Hard
Roofer	43	A little heavy	33	Heavy	26	Extremely hard
Roofer	53	Heavy	39.25	Heavy	28	Extremely hard

ACC: Absolute Cardiac Cost; RCC: Relative Cardiac Cost

Based on the data gathered, Frimat's coefficient of demand varied between a minimum of 7 and a maximum of 32 points. The average was determined at 22.55% and according to the classification of demand, findings showed 1 worker (5%) with minimum physical load, 1 (5%) with very light load, 1 (5%) with light load; 2 (10%) with bearable load, 2 (10%) with demanding load, 2 (10%) with hard load and 11 (55%) with extremely hard load. While applying Chamoux criteria regarding Absolute Cardiac Cost to assess the job of the 20 workers, it was found that demands were: 1 worker (10%) light, 9 workers (45%) very moderate, 5 workers (25%) moderate, 2 workers (10%) somewhat heavy and 2 workers (10%) very heavy.

Regarding Relative Cardiac Cost for assessment of the 20 workers' demand classification data retrieved indicated that 5 workers (25%) had light demand, 7 (35%) moderate, 7 (35%) heavy and 1 (5%) very heavy. The univariate analysis shows that the distribution of jobs that the 20 construction workers were performing at the time of the study is as follows: 10 builders (50%), 2 journeymen (10%), 1 electrician (5%), 2 plumbers (10%), 1 cleaner/finisher (5%), 2 painters (10%), and 2 roofers (10%).

Table 6 presents the qualitative results of the overall physical load in relation to the answers of each worker. However, for a better understanding of the results, the mode for each construction job was calculated, giving the following results shown in Table 7:

Table 7. Results obtained by analyzing the mode of Chamoux and Frimat's Criteria.

	MODE CHAMOUX CRITERIA		**MODA FRIMAT'S CRITERIA**
	ACC – Assessment of the Position	**RCC- Worker's Assessment**	
Builders	Moderate	Heavy	Extremely hard

Journeymen	Heavy	Heavy	Extremely hard
Electricians	Light	Light	Very Light
Plumbers	A little Moderate	Moderate	Hard
Cleaner/Finishers	Light	Light	Minimum workload
Painter	A little Moderate	Moderate	Hard
Roofer	Heavy	Heavy	Extremely hard

ACC: Absolute Cardiac Cost, RCC: Relative Cardiac Cost

It can be concluded that, according to Chamoux and Frimat's criteria, the occupations with the greatest demands are those of builders together with their journeymen and roofers with a heavy RCC and an extremely hard Frimat demand. [19] [20]. Regarding the perception of physical effort using the Borg scale, it was obtained that when analyzing each worker's 3 most important tasks, calculating the mode in the building tasks, the values were retrieved as heavy workload in both masonry and plastering/foundry; while for the journeymen, foundry was perceived as very heavy.

For the electrician, the activities of piping and wiring, as well as the laying of tiles were valued as heavy. The plumbers valued the installation of water and drainage pipes as very heavy, as well as the installation of water pumps. The cleaning and finishing worker also perceived his activity of cleaning floors, walls, and windows as very heavy. The painters, on the other hand, valued the filling task as very heavy and the roofers considered their tasks of placing Eternit sheets, tiles and hot waterproof sealing as very heavy.

In this study, it was observed that, despite the training and experience of the construction workers, according to the Frimat's criteria, 75% of the builders showed risk of physical overload and 50% showed said risk according to the relative cardiac cost index, which indicates that construction work implies high physical and energetic demand, especially among builders. It should be noted that with respect to roofers, 100% of them showed heavy relative cardiac cost, and, according to FRIMAT, their tasks are extremely hard.

The results obtained can be contrasted with the study performed by Maria Villagra and Carlos Torres who evaluated the physical workload of 9 builders in the task of building walls using conventional bricks and bricks that had greater weight and bigger dimensions, obtaining as a result that the highest energy demands were when working in the rows at floor level because of the most unfavorable body position and that the energy cost returned a difference according to the type of brick [21].. Regarding the limits in relation to the energy consumption level, the mean for consumption of kilocalories per day in all the construction workers was 2902.3 Kcal/day (median: 2197, interquartile range: 1046), which, according to Scherrer and Grandjean's classification, is

categorized as heavy workload at a global level [22].
With respect to builders, 75% showed a consumption of kilocalories greater than 2000 Kcal/8h, indicating that their type of work is severe according to Grandjean's classification of 1981, which would confirm Frimat's criteria, which classifies it as an extremely hard activity.
Likewise, in the research carried out by Zapata, Arango and Estrada with 41 stevedores to assess exposure to physical workload, it was determined that those who performed shoveling, stacking and unstacking tasks had high levels of exposure to physical workload, classified as demanding or even extremely demanding. This was established through heart rate measurement using Frimat's criteria. [23]. These findings could be extrapolated to the occupation of construction workers since their tasks involve handling loads.
In the assessment carried out using the Borg scale, it was found that builders and roofers perceive their tasks as heavy and very heavy, considering that they only have a 30-minute rest period within their 8-hour working day. It was found that, the greater the perception of the effort, the shorter the rest time. In addition, this assessment is in agreement with Frimat's; and this is confirmed by the studies carried out by Dominguez and others, where they determined that subjective perception is a good indicator of physiological work in master swimmers. On the other hand, in the multidimensional study carried out by Castañer and his team, the perception of the intensity of effort during physical activity was investigated. Conversely, the study by Naclerio and his collaborators focused on the control of strength training intensity through the perception of effort. [24].
During the course of this study, it was noted that builders and roofers do not take breaks during their working day, since they only have their lunch time, unlike electricians, plumbers and cleaners who take constant breaks because of their tasks. For this reason, it is advisable to take more breaks, even if such breaks are of short duration; therefore, it is advisab [25]le to implement breaks by calculating the rest or time for recovery using Lehman and Spitzer's criteria. [26] which is calculated with the following formula:

$$Tr = \left(\frac{Mt}{4} - 1\right) x\, Tt$$

Tr: time for recovery, in hours
Mt: Workload in Kcal/min
Tt: working time, in hours
Or Edholm's formula where Tr is time for recovery in minutes and M is workload in Kcal/min

$$Tr = \frac{480\, M - 2{,}000}{M - 1.5}$$

4 Conclusions

- It is concluded that heart rate monitoring is a reliable technique to evaluate physical workload, obtaining that the construction worker perceives different levels of physical load, being the builder and roofer occupations the ones where energy demands exceed energetic capacities. The work performed in these areas does not include adequate breaks for recovery, which can lead to fatigue and/or musculoskeletal disorders.
- During the study, it was observed that despite the fact that there are heavy loads, there is no established ergonomic aid for their handling and transport; therefore, the workers load them manually. Finally, the Borg scale is a useful tool for the perception of physical effort that can be used with workers to perform a preliminary assessment of the job.

5 Recommendations

- To carry out future research on psychological workload and thermal stress to which workers are exposed in their daily tasks, as well as their rest and conditions for recovery.
- To develop an epidemiological surveillance system of the physical workload requirement, which includes workload assessment, job rotations, medical checks, training, and breaks.
- To develop a training program in manual load handling.

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AENIT 2023

UTN Facultad de Ingeniería en Ciencias Aplicadas

Acceptance Letter

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On behalf of the INTERNATIONAL CONFERENCE ON APPLIED ENGINEERING AND INNOVATIVE TECHNOLOGIES - AENIT 2023, we are pleased to inform you that your submission ***" Physical work capacity and heart rate in construction workers"*** has been accepted for indexing in Scopus.

24 October 2023

PhD. Cathy Guevara

AENIT Editor in Chief

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