Personalizing Physical Effort Estimation in Workplaces Using a Wearable Heart Rate Sensor

Pablo Pancardo(✉), J.A. Hernández-Nolasco, Francisco D. Acosta, and Miguel A. Wister

DAIS, Juarez Autonomous University of Tabasco, Cunduacan, Tabasco, Mexico
{pablo.pancardo,adan.hernandez,francisco.acosta,miguel.wister}@ujat.mx

Abstract. Sensor technology for personalized physiologic monitoring contributes to health and safety in workplaces. Wearable devices represent an efficient way to capture physiological values to obtain individual efforts for each worker due to physical activities. Heart rate based ergonomic methods provide results that show drudgery of a work activity for each person. In this paper, we show some experiments that highlight the importance when using custom methods to estimate the effort of people doing physical work. Previous works have already validated some benefits in using sensor technology to estimate physical efforts and energy consumption in the workplace. The results in our experiments applied to cleaning staff demonstrate how important is to use personalized measurements for more objective effort estimation.

Keywords: Sensor · Monitoring · Heart rate · Personalized · Working

1 Introduction

This paper is related with the measuring of physiological parameters of individuals while performing daily or labor activities in order to preserve or improve health and well-being.

The ability to measure the metabolic rate of people in daily activities, allows to improve their health and well-being, this is because it is formally established that the metabolic rate of a person can be estimated based on their effort [2].

The importance of estimating the physical effort of a person during labor activities, it has a particular interest in the workplace, given that the effort to perform an activity is different for each person. Misallocation of an activity can affect a person's welfare and health. Workers may have risks associated with the disparity between high physical work demands and capacity/labor skills. These risks include: musculoskeletal disorders, cardiovascular disease, prolonged absences, stress, burnout and early retirements from the labor market [9]. Furthermore, physical strength assessment in ergonomics has additional benefits as: worker selection and placement and job design [8].

Generic methods known to estimate the physical effort do not take into account important physiological characteristics of individuals [1,14,16].

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For many years, cardiac cost and metabolic expenditure from physical labor are calculated using formulas and generic tables [1]. Physical exertion is then set, based on standards, such as maximum heart rate (220-age). While in many cases this may be agile and convenient, it is not always true, as in the case of overweight or adapted people (acclimatized) to perform an activity. It is necessary to develop methods that can provide higher accuracy for predicting energy consumption for a wide range of physical activities. This would allow a greater chance of being accurate when to compare them to scientifically validated methods as doubly labeled water method [5].

In this sense, we show the advantages of a method that takes into account a personalized measurement to estimate workers' physical effort.

Most available solutions for health monitoring offer a generalized physiological measurement, that is, by reference to generic formulas or tables that are not customized to individuals [2,14]. Many others solutions are focused on predefined activities such as walking and running without considering physiological parameters of each person, giving results not clearly differentiated [5,6].

Therefore, it is needed to analyze how different are results when applying a generalized method compared with a method where a personalized maximum heart rate is used (instead a generic formula (220-age)). We use a customizable ergonomic method based on heart rate measurements to estimate physical efforts during work activities. Results were compared with those obtained with a method not allowing customization. The advantage of the method that can be customized is shown in this paper.

The purpose of this work is to establish that existing standards in effort estimation, do not allow continuous monitoring of the effort that people make in their daily activities. This is because standard methods do not consider the use of emerging technologies for real-time monitoring and they are not conveniently customized since based solely on age. The proposed solution is an extension to Chamoux method that allows continuous monitoring effort, taking into account the particular physical condition of each person through measuring the heart rate. We evaluate the goodness of this proposal through a comparative study with the other two methods (Original Chamoux and Borg) [2,7]. From these results, we can state that heart rate reflects health conditions (sick, tired, acclimatized) but to our knowledge, this has not been proven objectively and formally. The review of recently published results, related to the world of work, does not show a formula that reflects all involved factors.

2 State of Art

For many years, cardiac cost and metabolic expenditure from physical labor are calculated using formulas and generic tables [1].

The use of a custom method becomes more important when monitoring physical activities that require a lot of effort, such as heavy lifting. Since such activities are those that can compromise the welfare and health of workers [15].

As is established in the ISO 8996 standard [11] for estimating metabolic cost, the use of heart rate is an option that provides an estimation of effort with a margin of error is plus or minus 10 %. This method of analysis is surpassed only by custom measurements that require the use of specialized equipment commonly available in laboratories. The latter very precise methods are: equipment of indirect calorimetry (oxygen consumption test using a mask) and doubly labeled water (water consumption and urine analysis).

While measuring heart rate is a valid option to estimate the effort which represents a work activity for an individual, it is also important to consider that there are other factors influencing significantly, such as environmental conditions (temperature and humidity), weight, age, acclimation, mental stress, personality, etcetera [3].

Related studies have shown that for estimation of effort activities ranging from light to heavy may be more convenient to use simultaneously sensors of various types, for example, motion and heart rate sensors [3].

2.1 Related Work

Some studies have been carried using technology for energy expenditure (EE) and activity recognition in the workplace. Hwang et al. [10] proposed a measurement approach in energy estimation field. It is expected to provide in-depth understanding and continuous monitoring of workers physical demands from construction tasks. Their solution was to use heart rate (HR) to estimate EE according to a linear relationship between HR and EE. Their proposal was to achieve reliable field EE measurement through automatic action recognition using an embedded accelerometer, and applying HR-EE relationships for corresponding actions with acceptable HR monitoring accuracy.

In [4] is made a review of currently available monitors that are capable of measuring total physical activity as well as components of physical activity that play important roles in human health. The selection of wearable monitors for measuring physical activity will depend on the physical activity component of interest, study objectives, characteristics of the target population, and study feasibility in terms of cost and logistics. Six main categories of wearable monitors are currently available to investigators: pedometers, load transducers/foot-contact monitors, accelerometers, HR monitors, combined accelerometer and HR monitors, and multiple sensor systems. They mention that future development of sensors and analytical techniques for assessing physical activity should focus on the dynamic ranges of sensors, comparability for sensor output across manufacturers, and the application of advanced modeling techniques to predict energy expenditure and classify physical activities.

Migliaccio et al. [13] used sensors to monitor physical bends performed by construction workers, so, it is identified those physical activities that can be risky to health. In this experiment, a heart monitor was used to detect high heart rates which were directly associated with a subject carrying a load. Fusing heart rate data and posture data provided the capability of differentiating safe from unsafe material handling activities. The main objective of this research was to assist future decision makers in designing ergonomically safe and healthy work environments.

All works mentioned above try to estimate energy expenditure based on recognizing the activity, our proposal is that instead of recognizing the activity, we should estimate the physical effort, so heart rate is a good parameter.

2.2 Heart Rate Based Methods to Estimate Physical Effort

In this paper we use methods based on heart rate because this type of parameter has a 90 % accuracy in estimating physical efforts, as it is stated in safety and health standards at work (ISO 9886) [11,17].

There are several methods that rely on measuring heart rate to establish which is the physical effort that a work activity can represent for people [12]. We selected two of them: Borg rating scale of exertion [2] and Chamoux method [7].

The Borg scale is widely known and applied in sport and medical domains, it is generic and based on a table where, if a person has a certain value of heart rate, then it has a certain level of effort, it is called rating of perceived exertion. In Table 1 the Borg's scale shows 14 (6 to 20) values grouped in six categories.

Table 1. Borg's scale

Scale	Description
6	No exertion
7	
8	
9	
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	
20	Maximal exertion

In order to interpret Borg's scale the numbers in left column correspond to the number of beats of one person during physical activity, divided by 10 and the corresponding value in right column is the perceived exertion (level of effort), for example, if a worker has 110 beats per minute, the level on the scale is 11 and it belongs slight effort. In this method, it is assumed that the maximum heart rate of a person is 220 minus his/her age in years. It is not required a real effort test, therefore, it is a generic value.

Otherwise, Chamoux [7] proposes a lesser-known method and as far as we know not frequently used. This method requires to measure resting and maximum heart rate for each person, taking into account several physiological parameters.

The method consists of two steps to estimate physical effort. This first step is to obtain labor activity's absolute cardiac cost (ACC), which is obtained using the average cardiac frequency (ACF) and the resting cardiac frequency (RCF) for a person at every moment. ACF is obtained from the average value of the frequency of the worker during a day of conventional job. RCF is obtained after a person has slept (8 hours) and is resting.

ACC is obtained subtracting the resting cardiac frequency (RCF) to average cardiac frequency (ACF) as shown in formula 1 [7].

$$ACC = ACF - RCF \tag{1}$$

The second step is to compute the Relative Cardiac Cost (RCC). Therefore, we should get Theoretical Maximum Cardiac Frequency (TMCF). Conventionally, TMCF value is obtained subtracting person's age in years to 220. The formula for RCC is 2 [7].

$$RCC = \left(\frac{[ACC * 100]}{[TMCF - RCF]} \right) \tag{2}$$

Effort levels for a worker according to the method of Chamoux are shown in Table 2.

Table 2. Different levels of effort for RCC under Chamoux

RCC	Effort
0–9	Very light
10–19	Light
20–29	A little moderate
30–39	Moderate
40–49	A little heavy
50–59	Heavy
60–69	Intense

Additionally, we decided to customize the Chamoux method, that is obtaining the value of TMCF parameter for each person. To do this, we asked each user to perform a maximal exercise stress test using an electric treadmill and we took the value of heart rate as their TMCF. We refer to this as a personalized Chamoux method.

3 Experiments

The tests were conducted on a university campus, potential users were teachers, students, office staff (administrative clerks) and janitors. As janitors are who perform activities that require physical efforts that can range from light to intense, they were selected.

In the experiments, a group of 20 research participant (cleaning staff) conducted a series of work activities and heart rate measurements were taken during that activities. These data sets were collected using a population of 20 participants; 11 male (28.4 $\pm$ 8.5 years, 171.8 $\pm$4.7 cm, 77.6 $\pm$ 13.09 kg, BMI 26.26 $\pm$ 3.77) and 9 female (28.7 $\pm$ 5.97 years, 161.1 $\pm$ 3.5 cm, 65.1 $\pm$ 11.4 kg, BMI 25.06 $\pm$ 4.45).

Three physical activities were defined for every research participants. These activities are described in Table 3.

Table 3. Activities in the experiments.

Activity	Description
Sweep the floor	One broom (1 Kg) was used in this activity. A hallway (42 m long $\times$ 0.5 m width) was the area to sweep. The volunteers started in one corner of hallway and sweep in overlapping strokes in towards the end of the hallway.
Washing windows	The total dimensions of the window were 110 cm $\times$ 90 cm. The research participants starting at the top and work down the window. This activity was executed in indoor environments.
Stacking chairs	Placing the entire stack of chairs had a short walk away (3 m). This activity was done using iron chairs (7 kg). During these activities were created several stacks, each stack with 8 chairs; all experiments were done in indoor hallway. Never were stacked more than ten chairs at a time.

Personal characteristics and physical conditions (such as age, sex, acclimation, physical condition, etc.) are attributes that are indirectly reflected when we measure maximal theoretical heart rate being their maximal personal effort for each user. Together with the heart rate at rest and individualized monitoring in real time during the execution of physical activities they allow customized estimations. During analysis, these characteristics results allow us to see that two people with similar characteristics do not necessarily perform the same effort to perform the same activity.

Heart rate was measured using a unobtrusive Basis B1 Fitness Tracker Band. Basis' precision is enough to know how many beats per minute has a user heart. Basis B1 measures our blood pressure, steps, intensity, and exertion of our workout, and sleep metrics. This device was placed on the hand of each worker. The first activity was to sweep a floor using a broom, the second activity was to clean glass windows with a rag and the last activity was stacking metal structure chairs.

Heart rate values used in all methods (Borg-Chamoux-Personalized chamoux) were the average heart rates during the activities.

Experiments related to three labor activities are shown in Fig. 1.

(a) (b) (c)

Fig. 1. Activities developed by workers: (a) sweeping floors, (b) cleaning windows and (c) stacking chairs

4 Results

In order to compare the resulting values of all methods tested, we made a mapping of the Borg's effort values (Table 1) with labels used in Chamoux method (Table 2). Scales 6–7 are No Exertion (NE), 8–9 are Very Light (VL), 10–11 are Light (L), 12 is A Little Moderate (ALM), 13 is Moderate (M), 14 is A Little Heavy (ALH), 15–16 are Heavy (H), and over 16 are Intense (I).

A frequencies analysis of results of physical effort of the participants obtained for each physical activity was included. In order to do this, we obtained some values describing the features of a collection of data from physical activities performed. For stacking chairs activity, Table 4 shows number of users for each effort level considering their BMI and Table 5 grouped by method and genre.

In both tables we can see that estimated efforts of people using Borg method are only two levels, Chamoux method classifies them into three levels, while our customized proposal classifies them into four levels. Borg method, classifies all people at levels very light (VL) and light (L), Chamoux classifies 20 % in ALM, as it only takes into account the age of the people, while the proposed method distributes 60 % of workers between ALM and ALH, this is because it takes into account personal maximum effort, in addition to the age of the individual.

Table 4. Number of users for each effort level during stacking chair activity, grouped by method and BMI.

Effort levels	Borg		Chamoux		Personalized Chamoux	
	BMI $<$ 25	BMI $\geq$ 25	BMI $<$ 25	BMI $\geq$ 25	BMI $<$ 25	BMI $\geq$ 25
VL	6	5	1	3	0	0
L	5	4	7	5	4	4
ALM	0	0	3	1	3	3
M	0	0	0	0	2	2
ALH	0	0	0	0	2	0

Table 5. Number of users for each effort level during stacking chair activity, grouped by method and genre.

Effort levels	Borg		Chamoux		Personalized Chamoux	
	Male	Female	Male	Female	Male	Female
VL	6	5	3	1	0	0
L	5	4	7	5	6	2
ALM	0	0	1	3	3	3
M	0	0	0	0	2	2
ALH	0	0	0	0	0	2

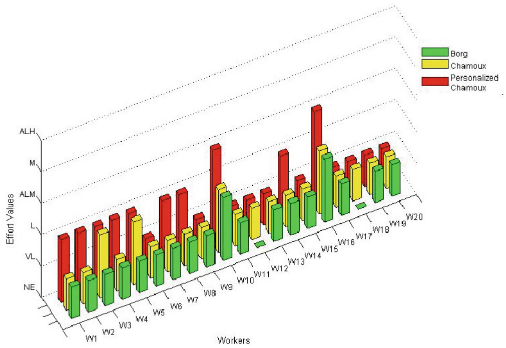
This indicates that our proposal has a better effort discrimination because of the measuring of their personal maximum effort.

These results can be used in decisions making to preserve or improve health and quality of life of the worker. This can be done by adjusting their work environment or by measuring physical performance based on their effort for a better allocation of their workload.

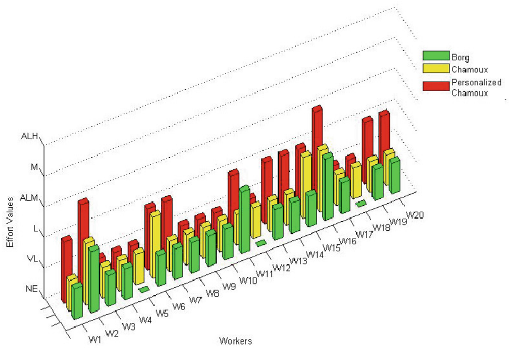
Figure 2 shows how Personalized Chamoux method is more efficient for estimating individual efforts, which is appreciated particularly for the activity of stacking chairs (Fig. 2). Using Borg scale all studied activities were classified as light or minor effort, while Chamoux shows that participants had differentiated efforts. Even more, using personalized Chamoux method, where TMCF is derived from maximal exercise stress test performed to each participant, efforts for stacking chairs vary from Light (L) until A little Heavy (ALH).

As we can see in Fig. 2, when we apply Personalized Chamoux method to estimate physical efforts, results reflect different effort levels for individuals even though they perform the same activity (because of their particular physiology). While the Borg method fails to reflect the different efforts that can represent the same activity for different people.

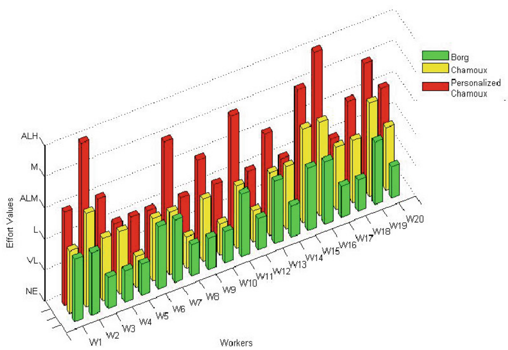
We have designed a prototype for logging and informing to users about their effort levels and historical records during activities. Figure 3 shows prototype for Android devices.



(a)



(b)



(c)

Fig. 2. Worker's Activities (a) sweeping, (b) cleaning windows and (c) stacking chairs

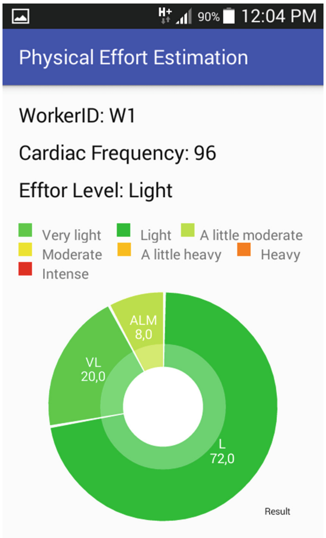


Fig. 3. Effort level prototype.

5 Conclusions

The contributions of this proposal are; the ability to measure the metabolic rate of people in daily activities, to improve their health and well-being, this is because it is formally established that the metabolic rate of a person can be estimated based on their effort. A standard effort can be estimated for each activity as a reference to analyze the gap with the individual effort to perform those activities; the usefulness of measuring the personalized productivity of workers in their work environment to improve enterprise productivity and the possibility to determine that a person is conducting its activities so appropriate i.e. in accordance with his personal capacities, abilities, and physical condition to improve performance, safety and welfare state.

This is not a proposal to accurately measure the physical effort, but emphasize the importance of customizing the measurement process and mention that it is hardly possible to have a generic method, given a large number of variables that must be considered. The intention is to show how the effort estimation varies when considering a custom value as the maximum personal cardiac frequency.

Analysis of our results reveals that an objective method of estimating individual effort should consider custom values in the parameters to capture the widest possible set of variables involved in the estimation of physical effort. Therefore, the decision to perform a stress test for obtaining maximum heart rate is important, because with this action, indirectly, we are including many factors as age, sex, BMI, acclimation, etc.

We consider as future work to evaluate branched equations techniques for combining data from these two types of sensors.

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