Workload evaluation of industrial work: existing methods and practical applications

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Abstract: The aim of this paper is to provide a study of the existing methods and devices to be put into practice for the workplace analysis in terms of workload evaluation. In fact, the design of the workplace can impact on the physical fatigue and discomfort perceived by workers, resulting in the reduction of work quality and the increasing of tasks time. In addition, the repetition of activities which imply awkward postures with considerable impact on fatigue can lead in a long-term to a higher probability of injuries and to the reduction of workers capability in performing the activity. In this paper, we put in evidence how existing methods for workload evaluation can be applied both during the pre-design stage and for the improvement of the existing workplaces. The value of this work is to provide companies of an overall view of all the existing workload evaluations, developed formulations and devices to be used for predicting the impact of the tasks workload on operators and consequently on the system performance. This knowledge helps decision-makers in determining the most effective design-level decisions. Finally, some practical examples of pushing, pulling and carrying activities evaluation are given putting in evidence the output that such devices can give to a practitioner.

Keywords: Workplace design, Workload evaluation, Human Factors.

1.Introduction

Wilson (2000) defines Human Factors (HF) as "the theoretical and fundamental understanding of human behavior and performance in purposeful interacting socio-technical systems, and the application of that understanding to the design of interactions in the context of real settings". The human factor is a considerable agent that has a relevant impact on the productivity both in term on time and quality in industrial contexts, especially in those ones that require several types of manual activities with a different level of experience and knowledge. In recent years, experts and practitioners have increased their research on the impact that human factors could have in final productivity to improve productivity and to guarantee better ergonomic conditions in the workplaces. Following as define in Otto and Battaia (2017) workplace ergonomics depends on three main aspects: physical, cognitive and organizational factors. The physical aspects play the most significant role and for this reason, they are also those ones most used by companies to evaluate the workers' ergonomic conditions. In fact, a better ergonomic workplace could guarantee a higher workers' well-being and increasing performance of the global organization. On the contrary, a poor ergonomic design of a general workplace can generate a large number of sick leaves due to musculoskeletal disorders (MSDs). In addition to these aspects, it is necessary to take into account the presence of highly skilled elderly workers not easily interchangeable with robots. In Europe, the number of people aged 65 or older is about to grow from 85 million today to more than 151 million in 2060 (EC, 2014). The EUROSTAT estimates that by 2060, 30% of the population of the 27 EU countries will be over 65 years old. This means that the ratio of productive individuals to retired people will be 2:1, versus the current ratio of 4:1. According to some estimation, about 44 million workers in Europe suffer from occupational musculoskeletal disorders . They represent the 38% of occupational diseases (EHSAW 2010) with a cost up to 2% of the Gross National Product in the EU (Battini et al., 2015). For these reasons, the increasing of ergonomics conditions is closely linked to a general reduction costs. Different studies have been conducted to define in which way a worker could be affected by MSDs. David (2005) provides an overview of the range of methods that have been developed for the assessment of exposure risk factors for MSDs. There are three main dimensions that can impact the physical work: level, time and frequency of different forces and shifts. Another important aspect to consider in the evaluation of physical work is the operator's characteristics and for this reason, it is very difficult to define a general model able to evaluate the execution risk of a task or work (Calzavara et al., 2018). Different studies have been conducted to evaluate in a quantitative way the risk associated to a particular type of work and different methods have been developed to analyze the ergonomic risk for a particular part of the human body (NIOSH, RULA, REBA, OCRA, EAWS are the most important). There are a lot of studies that demonstrate a link between productivity and ergonomics. Battini et al. (2011), Otto and Scholl (2011)introduce in different way some additional constraints to integrate workers' ergonomic conditions in assembly line balancing problem. Other studies focused their aim on the increasing workers' ergonomic conditions during the job rotation scheduling definition taking into account physical ergonomic risks as constraints (Otto and Battaia, 2017). Othman et al. (2012) proposed a model that minimizes the average worker's fatigue level taking into account also the minimization of costs and the number of fired workers with high performance. This work is also considered one of the first attempts to incorporate the human fatigue level in the planning process. The workplace design is one of the most relevant aspects evaluate by Botter et al. (2016) that conducts a study to define the main differences in postural, muscular and physical activities comparing two dynamic workstations to a conventional sitting and standing workstation. Neumann et al. (2006) identify production system design elements which can impact both in productivity and ergonomics in an automotive assembly plant. To evaluate workers' ergonomic conditions some researchers have been focused on the analysis of fatigue and operators' posture during the working phase through simulation environments. Savin et al. (2017), in order to integrate human fatigue in the workstation design, have evaluated three simulation environment that could be used as a tool to assist designers in considering movement variability to improve ergonomics at the workstation. Dode et al. (2016) develop an approach that integrates both human fatigue-recovery patterns and human learning into Discrete Event Simulation model to predict productivity and quality. While ergonomics can be evaluated following one of the different methods proposed in David (2005), the evaluation of the level of muscular fatigue accumulation the operator is experiencing by evaluating the percentage of muscular voluntary contraction (MVC) related to each activity. The level of MVC can be obtained with qualitative and quantitative techniques but not all of them can be applied easily. This paper wants to help practitioners understanding the existing ways of evaluating this value for helping them taking into account during the workplace design both the ergo indexes and the percentage of MVC related to each activity. The remainder of this paper is composed of following sections. Section 2 presents different ways to evaluate the workers fatigue level. In section 3 a general overview of existing methods for load evaluation is provided. In section 4 a comparison between heart rate evaluation and a dynamometer load calculation is provided and results are compared. Finally, in section 5 conclusions and future research are presented.

2.Muscular Fatigue

In this section, muscular fatigue concept is given and the main methods that can be used to evaluate it are briefly described. Muscle fatigue reduces the ability to exert a force in a voluntary effort. Reduction of forces and fatigue lead to ergonomic risks and work-related MSDs (Ma et al., 2009). The worker's fatigue level can also affect the final product quality and the production rate with a cost incrementation for the companies (Otto and Battaia, 2017). It is possible to define two main type of fatigue: general fatigue and muscle local fatigue. The general fatigue can be evaluated through the human energy expenditure index. In Garg et al. (1978) energy expenditure index for common manual tasks and body movements is evaluated and it is composed of two terms. The first one represents the energy required to maintain a body posture while the second one represents the energy required to perform a specific activity. A high energy expenditure is associated with a high risk of musculoskeletal disorders

Instead, the muscular fatigue can be quantified through the Muscular Endurance Time (MET) models. As defined in Imbeau and Farbos (2006), MET is defined as the maximum time that a muscle can sustain a mechanical load during a static exertion. Generally, the fatigue index is expressed as a differential equation, depending on the maximum voluntary contraction (MVC) and the external load or the forces to which the muscle is subjected. Muscular recovery is complementary to muscular fatigue accumulation.

Muscular recovery could be evaluated through the definition of rest allowances which is a strategy and a practical way to reduce the risk of WMSD. Rest allowance (RA) in static work represents the time needed for adequate rest following a static exertion and is generally expressed as a percentage of holding time, i.e., the time during which a static exertion, static posture or a combination of both is maintained without interruption (Rohmert et al., 1973). In Imbeau (2009) four different types of RA have been evaluated in different contexts to evaluate difficulties and limitations in their application. In Battini et al. (2015) the RA to define a new single-objective model where ergonomic and time are considered together in the assembly line balancing problem. The main difficulty in the application of RA is the non-linearity formulation and the impossibility to evaluate a priori the tasks conditions. RA is calculated to define the general recovery time and it considers all body. In some cases, it could be better to evaluate the fatigue level for only some muscles, in particular, those ones closely linked to the type of tasks performed by the operator. For this reason, the global energy evaluation could be not so useful and local muscular fatigue could be evaluated to define the worker's local ergonomic conditions. There are several aspects that impact in the local muscular fatigue. In Ma et al. (2009) the forces and torques applied to the human body are considered with the total load to carry or to move to assembly parts. Another aspect to evaluate is the repetitiveness of some tasks and the tasks execution scheduling. In order to reduce the local muscle fatigue, Michalos et al. (2010) propose a re-scheduling model that integrates workers' competences, fatigue, distance traveled, costs and repetitiveness of tasks. In order to decrease the local muscle fatigue, special tools have been created to generate particular job scheduling analysis and to underline the parts of the body more critical. To integrate workers' fatigue evaluation in the work design digital human modeling (DHM) technique has been used more and more in the industry taking human as the center of the work design system (Chaffin, 2002).

3.Existing methods for workload evaluation

As described in the paragraphs before, forceful exertions have been considered to be the most important cause of musculoskeletal disorders related to the upper extremity.

In the literature, there are different methods for assessing the magnitude of physical exertions, but not all of them can be put into practice during the design phase of the workstation. In addition, these methods can be grouped into qualitative and quantitative methods. The first are based on the prediction of the workload basing on subjective evaluations of the workplace or on predictions based on the workstation layout, the second rely on the data that can be recorded by using validated devices. Consequently, for a practitioner, it is not easy to establish which is the best method to be used for making decisions regarding the most effective design of the workplace.

3.1 Qualitative methods

Qualitative methods could consist of subjective evaluations which are based on verbal estimation given by the operators during the performance of the activity. The advantages of using such techniques are related to low costs in terms of money in comparison of the investment necessary for buying an instrument and in terms of time needed to understand how to use and how to test it in the specific industrial context. Moreover, as put in evidence in Borg (1990) subjective evaluations can give a feedback not only regarding the stress of the muscles and joints during the activity but also of the central nervous system. Despite these advantages, they are influenced by subjectivity and this leads to the difficulty of assessing the accuracy and the variability of the measure between different operators. In fact, the evaluation of an operator for the same load can be different if he performed previous physical efforts and he experienced fatigue accumulation on the muscles. In addition, the precision of the measure is different if the operator has previous exposure to the benchmark (Marshall et al., 2004). The accuracy of verbal estimation of the load can increase if the operator performed a maximum exertion before the evaluation of the intensity of the force related to the load (Marshall et al., 2004). According to this, in Jakobsen et al. (2014) it is analysed the relation between the exertion perceived by the operator with Borg’s scale (Borg, 1990) and the cardiovascular and muscular workload assessed with the ECG (Electrocardiography) and with the EMG (Electromyography) for lifting tasks. Subjective evaluations can be put in practice not only in the existing workstations but also in the design phase if the loads to be lifted, pushed or pulled are available or if they can be reproduced. In addition, it can be considered as qualitative methods the existing tools which can predict the workload and the time with the information regarding the layout of the workstation with simple biomechanical regression models and Methods-Time Measurement (Greig et al., 2017). This tool, which permits to estimate the %MVC, is a kind of observational method and can be put into practice easily in the design phase in a hypothetical virtual environment where the design input parameters are known. The disadvantage that such a tool has is that it can be applied only on workstations where the operator is fixed in a workstation and there is only the movement of arms and shoulders for assembling the item in the workbench.

Moreover, there is the possibility, for a practitioner, to apply digital human modelling simulation for estimating the load reproducing the real activity in a virtual environment (Massolino et al., 2017). The simulation permits to evaluate a task months before having the real components available or during the designing of the workplace. But the simulation tool needs to be further developed to be applied in an industrial context because more data need to be recorded in the field for different kinds of activities and there is the need of matching these data with the ones recorded with validated devices such as a dynamometer.

3.2 Quantitative methods

Quantitative methods are related to the real measurement of the load through the use of existing devices such as the EMG or the dynamometer. As put in evidence in Lee et al. (1991) the activity of pushing and pulling have an effect on the lower back. Generally, the pushing determines a smaller lower-back loading in comparison with pulling. For both the activities, there is an influence of the weight and height of the subject who has to perform the activity and of the handle height of the cart to be pushed or pulled. The body weight influences more the pulling than pushing and for each activity, there is a proper handle height for minimizing lower-back load (Lee et al., 1991). In addition, the cart characteristics can also affect the push and pull forces (Al-Eisawi et al., 1999). It has been put in evidence that the minimum push and pull forces are proportional to the weight of the cart and inversely proportional to the wheel diameter. Even more recent literature (Garg et al., 2014) has put in evidence the important factors that should be considered by industries in the design phase: the friction, wheel and weight and handle height of the cart, the grade or slope of the floor and the trunk posture, the feet placement of the operator and the pushing and pulling frequency and distance.

Consequently, for pushing and pulling activities it is necessary to carry on proper evaluations in each industrial field of application in order to understand the effect of such kind of activities for different operators with the use of different kinds of carts. For having these measures of load in an objective way the EMG and the dynamometer are the most used devices. Even though the measurement of the load with this kind of instruments is considered the gold standard, the reliability coefficient is 0.77 because different operators can perform the same activity with different techniques causing a difference in the actual force application (Bao et al., 2009). For example, the same operation can be performed with one or two hands and, as a consequence, the final force applied to perform it is different. The EMG is a tool used for detecting electrical activity in the muscles and it consists on the placement of electrodes on the skin surface above the muscle of which it has to be monitored the contraction in order to evaluate the % of MVC of the muscle during the performance of the activity. The disadvantages of the EMG are the influence of other muscles movements, of the interference of electrical supply and of mechanical problems on the recorded measurements of MVC (Turker, 1993). Even though a relationship has been found between self-reported load estimation method (such as Borg CR-10 scale) and the grip force measured with the EMG (Buchholz et al., 2008), there could be lack of correlation between the two measures due to the wording of the self-reported questions. Moreover, the questions could be not specific enough to match a single direct measurement. In addition, the EMG implies some problems related to the application because different individuals can use different groups of muscles for the same task and it is difficult to interpret the measure of MVC for multiple muscle groups. As far as the disadvantages are concerned, this technology is complex and costly to be applied in an industrial context.

The dynamometer is a tool to measure the peak and average force in kilograms for carrying, pushing and pulling activities. It is fixed to the object to be carried, pushed or pulled and any kind of slipping has to be avoided. Before the use, it is important to understand the direction of forces that represent the movement path of the operator (Massolino et al., 2017).

The application of this device is easy to be performed and from the output data, it can be revealed the kind of movement that the specific operator performed in addition to the influence of the height and weight of the item. The use of wearable sensors for evaluating physical fatigue in the workplace is becoming the focus of recent literature (Maman et al., 2017; Calzavara et al., 2018). Related to this, the combined use of heart rate monitor and accelerometers or inertial measurement units (IMUs) for assembly tasks and manual material handling tasks has been analysed (Maman et al., 2017). According to this, in the next Section, it will be carried on some practical applications of the dynamometer and of the heart rate monitor for pushing, pulling and carrying activities in order to show the output that such devices can give and how they can be used for understanding the muscular fatigue of operators. Moreover, some qualitative methods are put into practice for having a comparison of how the data related to the load level could change if these methods are chosen with respect to the quantitative ones. Even if the practical application of the next Section does not involve a lot of subjects, the aim is to put in evidence how future researches should be focused on this direction for understanding the best easy-to-use and effective way for workload evaluation.

4.Pushing, Pulling and carrying: dynamometer application and results

In this experiment, we conduct tests with a dynamometer to assess the force related to 3 activities: pushing, pulling carts and carrying items. The aims of this experiment are to assess the forces and the level of forces and to compare the dynamometer results to the results obtained by the heart rate monitor, Borg scale CR10 (Category ratio 10) (Borg 1990) and the Percent Maximum Voluntary Contraction %MVC. Pushing, pulling, and carrying an item are common tasks in several sectors in industry and services. Activity such as warehousing involves pushing, pulling, and carrying. Besides industrial activities, services such as shipment, luggage in airport and waste collection also involve that kind of tasks. Workers are exposed to musculoskeletal disorders and physical hazards when performing pushing, pulling and carrying or lifting activity. According to Garg et al. (2014), 9% to 18% of workers' low-back injuries are related to pushing and pulling activities and study also reported the relationship between pushing, pulling and shoulder pain.

The aim of this part is to introduce methods to evaluate the load of pushing, pulling, and carrying in order to evaluate the risks. The results that can be obtained with this experimental method could be used to design work and to compare the real load to the maximum load suggested in the literature, such as (Snook and Ciriello 1991). Another way to assess the physical exertion is Borg scale; it is a subjective evaluation on a scale to evaluate the difficulty of the exertion and the work.

• Pulling: In this experiment, we use a dynamometer to assess the force and a heart rate monitor to assess the heart rate. We execute pushing and pulling of carts and carrying an item for 5 m from a height of 1.5m. We execute the activity for several cycles. The subject of this experimental part is a man of 1.80 m high and a weight of 80 kg considered in the 50% percentile of worker population. Two different forces are included in each pulling (pushing) activity according to Snook and Ciriello (1991). To get the cart in motion, the force is called initial force (kg) and the force to keep the cart in motion is called the sustained force (kg). We report the evolution of load (kg) and the evolution of heart rate (HR) in Figure 1.

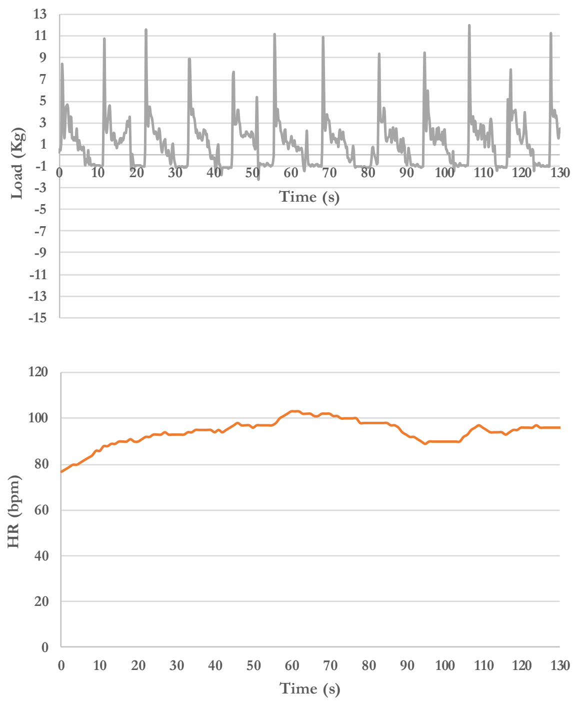

Figure 1: Monitoring of HR in bpm and of the Load in kg during the pulling of a cart

From Figure 1, we observe a periodic pattern with a pic of force at the beginning of the cycle. As observed by Ciriello et al. (1999) and the survey by Garg et al. (2014), pushing and pulling tasks require a higher initial force at the beginning of the effort. The heart rate monitor (HRM) shows that during the effort, the subject heart rate is high, however, the heart rate does not show any pattern of forces and hence, we cannot distinguish the pic of initial force with the HR.

- Pushing: The subject pulls a full cart for 5m each cycle from a 1.4 m height. We report the evolution of load (kg) and the evolution of heart rate (bpm) in Figure 2.

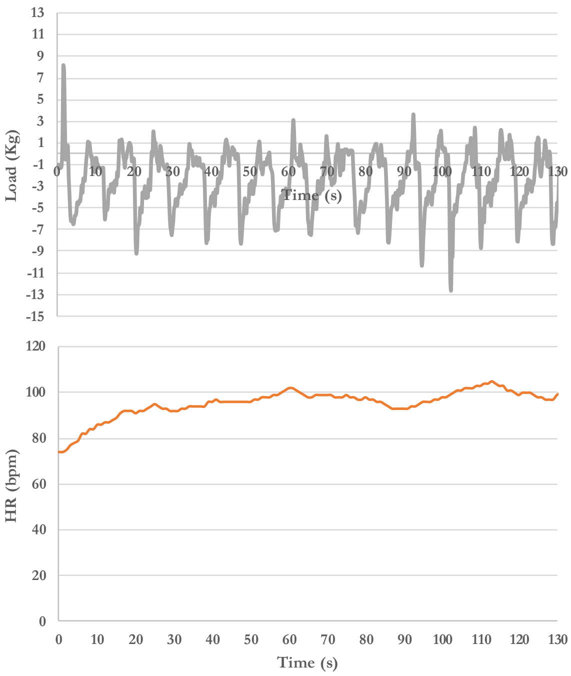

Figure 2: Monitoring of HR in bpm and of the Load in kg during the pushing of a cart

The evolution of the load and the heart rate conclusions are similar to the ones of the pulling activity. The pic of force is higher at the beginning and the load is negative because of the positive sense of the dynamometer, in pushing, we get a negative value. The heart rate is high along the exertion and reported as bpm along the activity.

- Carrying: For 200 s, the subject carries an item for a distance of 5 m.In carrying, the load is considered as static along the exertion and the load can be measured with the static assumption, the activity and its intensity could exceed the load limit of a worker. It is important to compare the result of the load in carrying with limit such as those defined by Snook and Ciriello (1991), this comparison is reported as %MVC in Table 1.

We propose in Table 1 different evaluation criteria of load, with Borg scale CR10, when we measure the subjective evaluation of load reported by the subject that exerts the effort. The dynamometer value is reported as the rounded mean value, calculated with the data from all cycle when the force in measured. The mean value is reported in (kg) and for the two phases of pushing and pulling, and only one value in carrying, when we suppose that the effort is static along the exertion. For (%MVC) we compare the value obtained with the mean dynamometer value with the maximum acceptable forces from Snook and Ciriello (1991) and express it as a percentage value, the maximum acceptable forces from Snook and Ciriello (1991) are considered as 100% value.

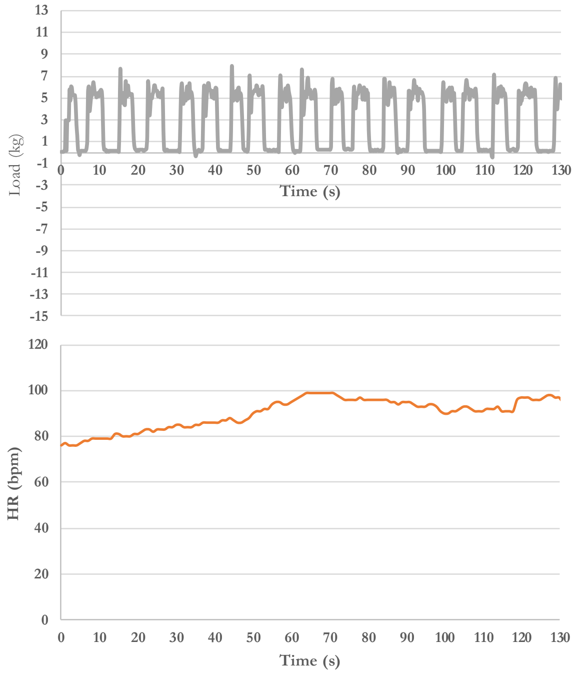

Figure 3: Monitoring of HR in bpm and of the Load in kg during the carrying of an item

Hence, we express the mean value obtained with the dynamometer and express it in percentage. We also report the mean value of heart rate (bpm) for pulling, pushing and carrying along the exertion. In general, from this experiment, the perceived effort evaluated with Borg scale corresponds to the %MVC, overall, the Borg scale estimation is close to the real man value measured with the dynamometer. Several studies from the literature showed the correlation between the perceived effort of Borg Scale and a measure of exerted force and some studies consider Borg scale with EMG to evaluate the effort. Assessing %MVC directly with EMG is difficult, especially in the design stage of the workstation. Using either of these methods such as Borg scale is a substitute for direct assessment and may be useful in the design stage. It is particulary interesting note that the heart rate median value tends to increase from pulling analysis to the carring one even if the dynamometer mean value and the %MVC tend to decrease. This counterintuitive phenomen could be linked to the frequency on which the activities have been done in the same period of time, in fact, as we can see in Figure 3 the frequency of the carring activity is higher that one linked to the pulling and pushing activity. However, additional tests could be useful to confirm this aspect.

5.Conclusion and future researches

From the literature, studies suggested that the HR and EMG are correlated with Borg scale (Chen et al. 2013). In this paper, we conducted tests to assess the level of load with a dynamometer for three activity, pushing, pulling and carrying. We also report a subjective evaluation of the load with Borg Scale and %MVC relative to Snook and Ciriello (1991) tables. The results suggested that the level of load could be estimated with direct assessment and also estimated with subjective evaluation on scale. The results obtained with our test still need further validation with large set of experiment and with subjects with different characteristics (age, gender, ..). However, the results show that the load of tasks could be estimated with subjective measure. In future work, we would investigate the correlation between different value expressed in this paper and compare them with large experiments database to assess their correlation. Regression and relationship between different methods should be relevant for workstation design, especially for industrial application, since measuring EMG signal are difficult and hard to assess. A measure such as %MVC and HRM could also be useful to balance workload between the different workstation and to assess the fatigue of workers after the exertion of effort. Moreover, these methods will be put into practice both in the real workstation and in the one reproduced through the use of virtual reality in order to suggest the most reliable method to be used in the design phase. In fact, in future researches the comparison of different workstation will be carried on for understanding how the design of the workplace can have an impact on the obtained results. Regarding to this, the advantages and disadvantages of each method in each field of application will be put in evidence with the final aim of giving to a practitioner the indication of the device or method to be used for each kind of activity that can be performed in an industrial context. In addition, these measures will be used to define the value of rest allowance and the number of cycle of works. This will be performed by considering not only the value of the load but also the physiological factors that distinguish one operator from the other. As far as rest allowance estimation is concerned, the value of rest allowance estimated with different measures (such as MVC and HR) will be compared for different kinds of muscular efforts for understanding the difference that can obtained with the application of different methods and the consequent use of different measures for the estimation of the time the operator has to recover. Regarding these future researches more insights in the physiological literature will validate the results.

	Borg Scale		**Mean rounded dynamometer value (kg)**		**%MVC**		**Mean HR (bpm)**
	Initial Force (CR10)	**Sustained Force (CR10)**	**Initial Force (kg)**	**Sustained Force (kg)**	**Initial Force (%)**	**Sustained Force (%)**	
Pulling	**5**	**4**	**10**	**5**	**62**	**50**	**88**
Pushing	**5**	**4**	**9**	**5**	**40**	**38**	**90**
Carrying	**3**		**6**		**35**		**92**

Table 1: Force exertion estimation with different criteria

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