Advanced Macroergonomics and Sociotechnical Approaches for Optimal Organizational Performance

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Exceeding the Recommended Energy Limits Due to Age and Gender in Occupational Aerobic Workloads

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ABSTRACT

The purpose of this chapter is to analyze the physical aerobic work in terms of the metabolic expenditure and compare it with the recommended boundaries of energy found in literature, proposing an alternative to the potential work overload through a compensatory equation introduced in the standard time of the workstation. To support the study, information considering the estimated metabolic expenditure in workers was applied to a novel procedure to reduce the metabolic demand of the task according to age and gender. Results of the study indicated that women older than 30 years exceeded the energy limits from moderate to very heavy load activities, and men older than 40 years exceeded the energy limits in heavy and very heavy workloads. The proposal of compensatory equation statistically reduced the energy loads below the recommended limits of energy. The aerobic workload is a sensitive factor for age and gender groups and can be potential risks for developing cardiovascular diseases as well as some musculoskeletal disorders.

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INTRODUCTION

Accurate methods are required to measure and control the efficiency of the industrial processes. Time and motion studies (TMS) provide the necessary information to establish proper time standards and obtain balanced workloads that allow workers to reach production rates. Because of the importance of the manufacturing companies to maintain appropriate productivity levels, standard time (ST) is considered as a key activity to control most of the production processes through the calculation of the work rate. In this respect, an increased work rate can expose operators to an elevated risk of musculoskeletal injury (Gooyers & Stevenson, 2012), and considering the aerobic physical capacity, ST might be inappropriate if it is performed by individuals who do not reach this capacity just because the age, gender or combination of both (Balderrama, Flores, & Maldonado, 2015).

Even though there is a fact of a significant difference to produce energy on individuals, just few evidence to consider age and gender was found in the calculation of predetermined times or some other systems used to determine the ST; Murrel (1965) proposed a fixed relationship to compute rest time considering an energy expenditure of 5 kcal/min for males and a 4.2 kcal/min for females no matter the age of the workers, and Mital and Shell (1984) proposed the use of an energy model to predict rest period as a percentage of working duration to compensate physiological fatigue, but without establish the application of the rest. Regarding rest pauses and line balancing, some intents to consider individual energy production have been experimented; Ayabar, De la Riva, Sanchez & Balderrama (2015), developed a model to estimate de energy consumption trough heart rate using linear regression and determine ST in moderate workload stations. Unfortunately, the study did not consider age and gender in the calculations.

It is important to remark that gender differences are significant in physiological work; in a longitudinal study during 5 years taking indices of work content, health, work ability, functional capacity, and symptoms of stress in 129 employees, women showed less physically able as men for physical work (due for reasons as the musculoskeletal capacity), and the critical age for women in prolonged physical work resulted in less than 50 years (Ilmarinen, 1988). Job demands could be significate in relation with older employees; lower autonomy and higher job demands increased the association of an array of common chronic health problems with sickness absence. These results were obtained taking in consideration work factors, health and sickness absence, and relative excess risk on 8,984 employees (Leijten, Van den Heuvel, Ybema, Robroek, & Burdorf, 2013). Likewise, a study performed in 2007 with 4 year, and 11 year examinations of 612 men using ultrasonography and the association between five measures of energy expenditure, concluded that high energy expenditures at work are associated with an accelerated progression of atherosclerosis even after controlling virtually all known cardiovascular risk factors, especially among older workers and workers with preexisting ischemic heart disease or carotid artery stenosis (Krause, Brand, Kaplan, Kauhanen, Malla, & Tuomainen, 2007). Workloads are then, an important part in the physical development of the worker; a 16-year follow-up study based on assessments of musculoskeletal and cardiovascular load, resulted in the following conclusion: In general, and contrary to what one might think, aging workers with low workload had better physical capacity than the subjects with high workload (Savainainen, Nygård & Ilmarinen, 2004).

With age, some physiological factors tend to change, for example, a research considering 120 men aged from 23 to 60 years old observed in six different type of work, found that the variation in the relative aerobic strain (RAS) is shown to increase in work tasks and is demonstrated that this increment is mainly related to physical work and the exposure of workers to peak loads (Ilmarinen & Rutenfranz, 1980). These variations can include the production of muscle forces and the coordination of motor
functions (Ilmarinen, 1984). The emergence of fatigue is one important reason for decreasing performance (Öztürkoğlu & Bulfin, 2012). In our experience, consequences of physical fatigue caused by high workloads can be associated with execution mistakes that will end in generation of scrap, repairs, idle time, process delays, and other manufacturing costs related to the personal performance. Also, a decrease in the efficiency and the product quality may appear at a short or long term.

Taking into consideration the metabolic rate needed to perform a job, an experiment is presented to investigate the industrial workloads performed by people of age and gender and compare them with the recommended energy limits at work extracted from literature. In addition, a time allowance equation is proposed in order to reduce the energy consumption in the participants; the equation (explained in section of: Time Allowance Equation) includes nine physiological factors and is introduced directly into the calculation of the ST.

**Aging and Work**

It is a noteworthy finding in the literature review that there is a decrease over the years to produce energy, as well as there is a difference between men and women in the capacity to consume (O2). For example, on an average, the physical working capacity of women is about 30% less than men of the same age (Astrand & Astrand, 1978). The decline in physical working capacity from the age of 20 to 65 years is about 30%, calculated in terms of mean value. This mean value for a 65-year-old man is of the same magnitude as the value for a 20-year-old woman (Astrand, 1988). Considered to compute physical shape and an accurate tool according to ISO 8996 (±5%), the VO2max (Maximal Oxygen Consumption) decline begins after reaching the maturity age, at least after 30 years of age (Shvartz & Reibold, 1990). Nevertheless, females often dominate jobs where major physical risk factors such as repetitive work, forceful exertions, static work, and awkward postures prevail (Collins & O’Sullivan, 2010).

Shephard (2000) findings, are specific in terms that “aging is associated with progressive decreases in aerobic power, thermoregulation, reaction speed, and acuity of the special senses. These changes can reduce productivity, particularly in self-paced activities where the physical or mental input of the individual worker is the rate-limiting step in production” (Shephard, 2000).

Many years ago, an energy consumption of 5.33 kcal/min for men and 4 kcal/min for women was suggested as a limit for 8 h shift. This represents one third of average consumption in the United States (Bink, 1962) and is still in use to determine energy loads and rest pauses (Bridger, 2003; Groover, 2007; Niebel & Freivalds, 2003). A workload of 5.33 kcal/min generates an increase in the heart rate (HR) of 40 beats/min (Grandjean, 1988). Other studies have recommended that the requirement for a physical activity should be between 30 (no rest available) and 50% (rest available) of the maximum capacity of the worker (Ilmarinen, 1984; Bridger, 2003; Astrand, 1956; Jorgensen, 1985; Rutenfranz, Ilmarinen, Klimmer, & Kylian, 1990).

Half of the aerobic capacity cannot be surpassed because when a demand of energy is involved, it is necessary to design tasks below its consumption level (Farrer, Minaya, Niño & Ruiz, 1997). At intensities exceeding 50%, carbohydrate metabolism increases and therefore, the degree of exertion gradually increases, HR and pulmonary ventilation per liter of oxygen uptake increases, and body temperature rises above 38 °C (Astrand, 1988).

Taking in consideration the information reviewed, is important to define that if there is a significant difference in energy production between women and men as well as a difference in workers of different
Exceeding the Recommended Energy Limits Due to Age and Gender in Occupational Aerobic Workloads

ages, then an adult woman should not perform a task with aerobic load for the same amount of time than a young man.

Determine the Metabolic Rate in Tasks

There are different methods used to estimate the energy consumption at work. Direct calorimetry is the most accurate method with minimal error but is often expensive and difficult to be used in the field. Similarly, doubly labeled water is accurate and expensive and is applicable for measuring energy consumption over long periods of time. The most recognized and accurate indirect measurement method is through reading VO2. For the ISO 8996 (2004), VO2 measurement is accurate to ±5%, while the methods based on tables, HR, and classifications are accurate to ±15%. The Firstbeat’s beat-by-beat method uses the HR also and reports better accuracy against other methods (Firstbeat Technologies, 2017).

By monitoring the HR, we can approximate the metabolic level of a person when executing a task. Taking into consideration the HR in basal state, it can be subtracted from the HR when an aerobic task is performed. VO2 has a lineal relation with HR when an aerobic task is carried out (Groover, 2007; Astrand, 1960; Ilmarinen, 1992; Manero & Manero, 1991; Smolander, Juuti, Kinnunen, Laine, Louhevaara & Männikkö, 2008). HR is acceptable as an estimator of VO2 only when the test work closely resembles the muscle work in the job (Oja, Ilmarinen, & Louhevaara, 1982), and is a good predictor when heat stress is present (Imbeau, Desjardins, Dessureault, Riel & Fraser, 1995). Bouchard and Trudeau suggest good reliability of the VO2/HR relationship at HR usually found in workplaces, regardless of the time of day, is not affected by a day at work in both genders (Bouchard & Trudeau, 2007).

Balderrama et al. (2010) evaluated an electronic HR monitor equipment to estimate oxygen consumption in aerobic activities. The HR monitor records every second and computes the VO2 through neural nets. The software uses a model developed by the company called Firstbeat Technologies (2017). A validation was performed by means of a comparison between a direct measurement equipment of VO2 and monitoring equipment of brand Sunnto resulting in no significant differences using a 95% of confidence level.

In order to determine how demanding is a work task in terms of VO2, there is a general classification presented by Astrand and Rodah (1977), where a workload is considered as a light load when VO2 is between 0 and 0.5 l/min (0–2.5 kcal/min), a moderate workload is considered from 0.5 to 1.0 l/min (2.5–5.0 kcal/min), a heavy work is considered from 1.0 to 1.5 l/min (5.0–7.5 kcal/min), a very heavy work is considered from 1.5 to 2.0 l/min (7.5–10.0 kcal/min), and an extremely heavy work is considered from more than 2.0 l/min (>10.0 kcal/min).

Work Rate

In industry, it is common knowledge that work rate is an important measurement of labor because the number of parts produced per hour or per day is one way to control the intensity of work. Companies use this rate to program their production volumes and determine its maximum capacity in relation to the number of workers and equipment available. ST is used as the basis for estimating work rate and is composed by the normal time and a group of allowances applied according to the work conditions. The normal time is the average time to perform a work task that can be determined by stopwatch, statistical data, video analysis, or predetermined motion time systems. Normally, it is determined from the measure
**Exceeding the Recommended Energy Limits Due to Age and Gender in Occupational Aerobic Workloads**

of average skilled operators. In any case, the obtained time represents a mean time of the cycle time without taking worker’s age and gender into consideration.

Allowances adding to the normal time are for personal needs (such as washroom and coffee breaks), unavoidable work delays (such as equipment breakdown or lack of materials), and worker fatigue (physical or mental) (Niebel & Freivals, 1998). In some cases, different compensations are added to the normal time of the job that help to reach the estimated time when factors do not allow to carry out the task in the calculated time (Meyer, 1991). Predetermined motion time systems are not suitable for aging workers and middle age and old woman can have problems to reach the ST in terms of energy consumption (Balderrama, Flores, & Maldonado, 2015).

Several factors can be utilized to establish allowances due to fatigue; according to the International Labor Organization (Kanawaty, 1992), the physiological factors are weight, force or pressure, posture, and restrictive clothing. The psychological factors such as discipline, concentration, mental and visual demands, and monotony can also be taken into consideration. Also, thermal and atmospheric factors of the environment such as temperature, humidity, wind conditions, noise, vibration, light, and visual factors are aspects that affect the personal performance when they are out of the comfort limits, which are considered as significant, in order to add extra concession to the normal time of the job. Unfortunately, there are no records or investigations that consider the age and gender differences as a required element within the ST.

**METHODS**

**Subjects**

Five companies dedicated to manufacture auto parts were visited, where a total of 149 workers gave authorization to collect data during 8 months of work in accordance with the institutional occupational standards. Their ages fluctuated between 20 and 68 years and were categorized in five different age ranges. Workloads as moderate, heavy, and very heavy tasks were considered according to Astrand and Rodah (section of: Determine Metabolic rate in Tasks). Considering a previous laboratory study (Balderrama, Flores, & Maldonado, 2015) about energy consumption, light tasks were not considered because they didn’t affect any age group. A summary of the participants’ data is presented in Table 1. Mean and standard deviation is presented considering five age groups to include 149 participants. 59 men and 90 women with a mean of 53.42 and 43.91 years old respectively. VO2 on rest as well VO2 MAX looked very similar comparing average measures for both genders. Due to some activities are time consuming and interfere with production purposes, rest VO2 was computed by equations according to age and gender (Kanawaty, 1992) and VO2max was taken from local tables (Sandoval & Ramos, 1995).

**Instruments**

Considering that VO2 is one of the most accurate methods to measure the capacity to generate body energy and the need to operate noninvasive equipment to workers, this study use an estimation of VO2 by means of HR using the Firstbeat technology (2017) as a new HR variability-based method for the estimation of oxygen consumption without individual laboratory calibration; it was examined as a good estimator in Smolander et al. (2008), Balderrama et al. (2010), and Uusitalo (2011). This equipment
Exceeding the Recommended Energy Limits Due to Age and Gender in Occupational Aerobic Workloads

Table 1. Participants' data

<table>
<thead>
<tr>
<th>Age Range</th>
<th>Gender</th>
<th>Number of Participants</th>
<th>Age (Avg)</th>
<th>Weight (Avg)</th>
<th>Height (Avg)</th>
<th>Rest VO2 ml/kg/min</th>
<th>VO2 Max ml/kg/min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Men</td>
<td>12</td>
<td>26.40</td>
<td>73.00</td>
<td>170.92</td>
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<td>38.90</td>
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<td>66.74</td>
<td>157.14</td>
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<td>35.76</td>
</tr>
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<td>25.60</td>
<td>68.34</td>
<td>160.66</td>
<td>3.84</td>
<td>37.30</td>
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<td>30-39</td>
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<td>14</td>
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<td>173.64</td>
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<td>31.47</td>
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<td>34.42</td>
<td>74.08</td>
<td>157.38</td>
<td>0.40</td>
<td>5.53</td>
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<tr>
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<td>37</td>
<td>34.78</td>
<td>75.03</td>
<td>163.08</td>
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<td>172.06</td>
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<td>31.22</td>
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<td>72.50</td>
<td>160.38</td>
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<td>69.50</td>
<td>154.33</td>
<td>3.36</td>
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<tr>
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<td>69.66</td>
<td>161.33</td>
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</tr>
<tr>
<td>Total</td>
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<td>59</td>
<td>53.42</td>
<td>75.35</td>
<td>170.06</td>
<td>3.77</td>
<td>31.31</td>
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<tr>
<td></td>
<td>Woman</td>
<td>90</td>
<td>43.91</td>
<td>69.96</td>
<td>157.54</td>
<td>3.58</td>
<td>30.96</td>
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<tr>
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<td>13.77</td>
<td>8.56</td>
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</table>

was utilized to obtain VO2 on field and compute time allowances by means equation 1 described in the next section. Also, a Sunnto Team Pod© with chest straps and Sunnto Monitor© software were used to monitor HR and calculate VO2.

Time Allowance Equation

An equation that considers individual energy production was formulated. The model considers the energy requirement for the task and compare it with the energy available of the worker (according to age and gender). The objective was to reduce the energy consumption below the recommended limits at work adding more time to the execution of the work task. The equation proposed uses the current energy expenditure in work task (GE) minus the resting metabolism rate of the worker (Eir), divided by half the maximum capacity (expenditure limit) of the person according to age and gender (Eid), minus, once again, the resting metabolism rate (Equation. 1).

\[
TOL = \frac{(GE-Eir)}{(Eid-Eir)}
\] (1)
The units of the model are relative to body weight in ml/kg/min. The necessary factors for calculating allowance factor (TOL) are as follows:

1. Age
2. Gender
3. Body weight
4. Smoking
5. Physical shape of the individual
6. Metabolic rate (Eir)
7. Capacity in terms of: Maximum oxygen consumption of the individual (Eid x 2)
8. Expenditure in work task (GE)
9. Workload level

The age (A), gender (B), body weight (C), smoking (D), and physical shape (E) were obtained directly from the participant and was fed in the Sunnto software that computes the energy consumption. Because it was not possible for most companies to allow direct measurement of the resting metabolic rate and VO2max of the worker directly, we made use of the equations for obtaining basal metabolism (F) published by the International Labor Office (Kanawaty, 1992); these are based on the age ranges and gender of the people. For VO2max (G) in people of different ages, tables of local statistics were used (Sandoval & Ramos, 1995). The tables mark a difference in VO2max according to age range and gender. In the application of equation 1, it is required that conversion units of basal metabolic rate and the maximum capacity for producing energy be the same (e.g. kcal, VO2, Watts, etc.). The 50% of the VO2max is only considered when rests in the occupational activities are available; otherwise, 33% of the VO2max must be used. The energy expenditure in work task (H) was obtained by direct measure of participants using the Sunnto Team Pod. The workload level (I) was obtained after GE (H) calculation according with Astrand and Rodah classification presented the first section of the document. At least, 20 cycles were taken on each activity.

The factor obtained from equation 1 must be multiplied by the normal time (cycle time) of the workstation in order to obtain the ST of the operation. That is, if the normal time is 80 s and the calculated allowance computed by personal data in Equation 1 is 1.033 then the new ST would be: 80 x 1.033 = 82.64 s. It is important to remark that equation variables (Eir, Eid, and GE) can be calculated by different methods according to the data and the availability of the resources. ISO 8996 provides different estimation methods regarding metabolic rate.

Procedures

Measurements were taken on repetitive tasks that possessed an aerobic load from a moderate to very heavy level. Physiological factors such as age, gender, weight, smoker, and physical condition level were collected at the beginning of a shift, as well as an explanation on how to wear the chest strap. In the first part of the experiment, production lines were monitored considering the actual ST with no modification in the process, and information that contained unexpected interruptions to the process was discarded. The first collected data were used to classify the workload level.
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Data obtained from chest strap was stored in a laptop, while the VO2 was calculated using the software for the estimation of metabolism, which was validated previously (Balderrama et al., 2010). Thereafter, the average consumption of the oxygen was calculated for each worker (GE) and then subtracted from the allowed oxygen consumption according to his or her age and gender (Eir). To determine the allowed oxygen consumption, international recommendations were taken into consideration to compare whether work tasks exceeded the 50% of VO2max (33% if rest are unavailable). Thus, VO2max was calculated using the local tables that were published by the Institute of Social Security (Sandoval & Ramos, 1995).

After detection of the workstations that exceeded the recommended limit (exceeded the 50% of VO2max), ST was modified by adding the time that includes the calculated allowances. This procedure was developed to evaluate the proposed equation. To implement the new ST increased in time, some strategies have to be taken to avoid affecting the work rates of the shift; more workers to the production line or more stock were introduced to the workstations. All the activities were performed to meet the requirements presented in Time Allowance Equation section. It should be noted that this study decided to disregard light workload activities due to a previous study (Balderrama, Flores, & Maldonado, 2015) that did not give significance of this level of activity.

Statistical Analysis

A total of five analyses were considered in the experiment: (a) a general linear model of analysis of variance (ANOVA) was carried out using the data of the VO2 in the task; the purpose was to determine whether age, gender, and other factors were significant factors that affect the energy expenditure of the task; (b) a paired t-test was conducted in order to detect whether the workers surpassed the recommended limits of the energy consumption in the workstation according with age and gender. Age groups split in male and females were compared with the average energy consumption on each work station; (c) a similar paired t-test test was developed, but this time, the data of VO2max of men from 20 to 30 years was introduced in the analysis; the reason, to simulate the work performed only by young male workers and figure it out whether they surpass the recommended limits of work; allowances were collected to run (d) a normality test to the results; (e) lastly, a paired t-test to analyze whether the new standard time with time allowances introduced, could reduce the energy consumption below the recommended limits. Minitab Software© was utilized to analyze statistical data including all the figures presented.

RESULTS

Results are presented according to the statistical analysis proposed in chapter 2.5 taking the same letters sub-division:

1. The ANOVA in the first part of the experiment reflects that only the factor introduced as workload level was a significant factor with a p value of 0.017. In other words, the variables introduced as age (p = 0.067), gender (p = 0.567), physical shape (p = 0.740), and smoking (p = 0.100) do not modify the response variable when a confidence level of 95% is used. Hence, the worker energy consumption (VO2) in workstation is not significantly different from one person to another and is only affected by the intensity of work.
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2. The paired t-test conducted to detect whether the VO2 in the task exceeds the allowed VO2, showed information to deduce that there is enough evidence to say that the VO2 required by the task is higher than the allowed limit (exceeded 50% of the person of maximum energy production) of the VO2 with a p = 0.0. The individual paired tests that considered age and gender in the three different workloads reflect that women older than 30 years surpass the recommended energy limits when they perform moderate, heavy, and very heavy tasks (according with Astrand and Rodah, 1977), while men older than 40 years surpass the recommended limits with heavy and very heavy tasks. In addition, women younger than 30 years surpass the limits in heavy and very heavy task, and men older than 40 years surpass the limits only in very heavy tasks. Figure 1 displays the difference of gender, age, and workload level when a limit of energy is considered. Values close to zero represent better energy to perform a task.

3. Results of the conducted simulating the workers having the VO2max of men in age ranging between 20 and 29 years, reflect that statistical evidence exists to deduce that young workers did not exceed the recommended limits of the energetic expenditure in all the considered workloads levels (p = 0.0). Figure 2 presents how the energy consumption can be below the limits if all the participants were younger men.

4. A residual normality test was conducted in order to validate the experiment obtaining a p value of 0.242 indicating normality in data.

5. Paired t-test performed after the application of the allowances indicates that the energy consumption of the workers did not surpass the energy recommended for 50% of their maximum VO2 (p = 0.00). Figure 3 shows a lower tendency of the VO2 after application of time allowances against results at the beginning of the experiment.

Figure 1. VO2 workload and recommended energy comparison
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Figure 2. Energy comparison considering 20–29 years energy level

![Energy comparison graph](image1.png)

Figure 3. VO2 workload versus VO2 with time allowance

![VO2 workload graph](image2.png)
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DISCUSSION

This investigation confirms that workstations that possess similar workload, have no significant difference in the worker energy consumption in spite of the physiological conditions of the person. In other words, all persons have similar energy consumption in similar tasks, but the main difference is based on the fact that we have different capacity to generate energy during the day. This result matches up with Louhevaara (1999), Ilmarinen (2001), and the definition of ISO 8996, which states that the metabolic rate can vary from person-to-person, about ±5%, for the same work and under the same working conditions. Also, we confirm, and according to the bibliography presented, that men and women have significant differences in energy production as well as the reduction in energy production after the age of 30 years.

Results of this experiment regarding aerobic workloads that are controlled by ST let us to assume that moderate workloads (2.5–5.0 kcal/min) might be unsuitable for women who are older than 30 years. Heavy (5.0–7.5 kcal/min) and very heavy workloads (7.5–10.0 kcal/min) could be unsuitable for women who are older than 20 years. Similarly, men older than 40 years surpass the recommended limits in workstation over the 7.5 kcal/min.

In accordance with the aforementioned information, workloads determined by the ST are not suitable for all ages and gender, proving that they are only be accepted for specified age ranges. The proposed equation applied to ST reduced the worker energy consumption below the recommended limits suggested in bibliography that mention that workloads should be below of the 50% of the worker capacity to produce energy in one day.

Metabolic capacity of young individuals can be significantly different to carry out tasks with high metabolic requirements compared with adult workers. According to our experience, some companies take strategies to not assign high workloads to adults and women or assign breaks according to manager experience to achieve the recovery of worker, where there is nothing normative or mandatory on this respect. Systems in industry designed to introduce brakes or rest pauses do not consider age and some companies assign pauses according to administrative interests and not when the operator needs it. An allowance of time within the standard time could be a good response to high working demands due the manipulation of the rest by worker each cycle time, achieving a recovery rate throughout the workday in better manner than rest pauses.

CONCLUSION

ST is a valuable planning tool for several important production factors; however, it could affect people depending on their age and gender. The addition of time through a ST allowance helps to accomplish manual aerobic work more equilibrated according to the amount of energy a person can produce. To implement compensatory equation, the acceptance of the problem and its implementation willingness is required. Depending on the production process, the allowances can be introduced individually or according to the characteristics of small working groups. The proposed equation differs from other models because it considers the age and gender of the employee and the feasibility of applying it systematically through ST.
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The recommendation of this study is to provide opportunities to the workers to keep energy reserves at the end of the shift in order to succeed on their day-to-day life, to enhance the quality of their lives, and to promote an occupational health program to improve the productivity of the manufacturing companies. Inclusion of the aging people must be one of the commitments of this era due the worldwide increment of old people.

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