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Maximum acceptable work time for the upper limbs task and lower limbs task

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Abstract

The physical workload is a major occupational risk factor for workers. Currently the used methods to assess physical dynamic work load only consider working with the whole body and do not discriminate the load on each of the body segments. Determine the maximum acceptable dynamic work time when the work involves the whole body, the upper limbs and the lower limbs. Heart rate and oxygen consumption measured by ergospirometry were monitored in 30 workers exposed to various loads executed with the whole body, legs and upper limbs. Anaerobic threshold was determined by respiratory quotient. This was used to calculate the acceptable dynamic work time. Statistically significant differences between acceptable dynamic work time for upper limbs and lower limbs were found. A negative exponential correlation was found between the work load time, the oxygen consumption and the heart rate. R> 0.9 in all cases. Six regression equations were proposed to determine the acceptable dynamic work time. The acceptable dynamic work time for lower limbs and whole body was similar. The acceptable dynamic work time for upper limbs was significantly lower than acceptable dynamic whole body work time. The relative heart rate seems to be the best indicator to measure acceptable dynamic work time.

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Keywords: Oxygen uptake; Work load; Acceptable work time; Occupational health; Ergonomics

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1. Introduction

The physical work load can be measured considering oxygen consumption (VO2) or heart rate (HR) [1, 2]. This one is a very accessible variable for monitoring and is frequently used to determine the energy consumption in different workplaces. That's why it is a broadly used method for the measure of physical activity at work, even if it is influenced by weather and mental stress and other factors that can introduce bias. [3, 4].

The relationship between HR and VO2 has been deeply studied [5]. It is been demonstrated the direct relationship between both of them [1, 5, 6, 7, 8, 9, 10]. The relative cardiac cost index (RCCI), lead to a more adjusted estimation of the response to a work load [9, 11, 12, 13].

$$RCCI = \left(HR\ work - HR\ rest \div HR\ máx. - FC\ rest \right) \times 100$$

HR work = heart rate of the work.
HR rest = heart rate of the rest.
HR max. = maximal heart rate. It is calculate by (200-age).

An acceptable work load is defined as the equilibrium between the physical work load and the cardiovascular and respiratory response [14]. This concept can be applied to determine the maximum work time (MAWT), defined as the maximum quantity of time along and individual can support a work load without fatigue.

The energetic work limit is an indicator that includes the physical capacity of the individual and the behavior of the occupational activity. Also it is useful for the work system design and the pauses regime [15].

Some studies probe the usefulness of this method in the analysis and characterization of the physical work load [16, 17, 18]. These studies observed the global physical work load and do not consider the body segments. The dynamic physical load risk requires however the assessment of body segments. The present research aims to generate indicators to measure precisely the risk when the work is mostly done with the upper limbs and with the lower limbs.

2. Methods

Thirty young and healthy workers participated in this study (17 women, 13 men).

An ergo-spirometer Cosmed K4B2 was used for the assessment of oxygen consumption, CO2 production, basal metabolic rate, respiratory frequency, heart rate and respiratory coefficient [19]. Before each evaluation a calibration of the equipment with gases mixture for the analysis of O2 and CO2 was done.

For the evaluation of upper limbs a Monark hand grip cycle ergometer was used and for the assessment of lower limbs a Monark pedal cycle ergometer.

2.1. Oxygen consumption and heart rate test

The Basal heart rate and the oxygen consumption were measured in a noiseless room (<60 DbA) with 22o C (+/-1o C) of average temperature of the air. The time of the day, elapsed time since the last food intake and the physical activity performed 24 hours before the test were registered.

The criteria for the evaluation of the maximum consumption of oxygen were that each individual reached at least 90% of the theoretical maximum heart rate (220- age), a respiratory coefficient higher that 1,1 and presence of plateau at the peak of the slope with no apparent growth.

For lower limbs and total body assessment the test were performed administering 50W two minutes duration loads [20]. The first load had a 60 rpm rhythm.

For upper limbs the first load was 25W with growing increases of 25W, two minutes duration and 60 rpm rhythm.

Maximum acceptable time assessment:

1) The load at which the maximum VO2 was obtained was taken in the protocol for upper limbs and lower limbs.
2) The calculation of the 50%, 40%, 30% and 20% of the maximum load obtained for the test with lower limbs and upper limbs was performed.
3) Each individual was evaluated during four consecutive days for upper limbs and for lower limbs with continuous workloads until reaching a risk level. This level was set considering the respiratory quotient and / or the decision to suspend the test due to fatigue in the individual evaluated. Individuals had a break for two days between upper and lower limbs assessment.

2.2. Statistical analysis

For the analysis the SPSS predictive analytics software V 13.0 was used. Student's t-test and Shapiro-Wilk were performed. The heteroscedasticity was evaluated.

Statistical significance level $\alpha = 0.05$ was established. A p value less than 0.05 was considered statistically significant difference.

3. Results

The average age of the population was 24 ± 3.7 years, ranging between 22 and 37 years. No statistical difference between the ages of men and women were found.

The mean body weight of the participants was 65.8 ± 7.7 Kg. The gender difference was not statistically significant.

The maximum oxygen consumption was between 20.5 - 41.2 ml / kg-min with a mean of 30.4 (+/- 5.5 ml / kg-min).

The maximum oxygen consumption in the upper limbs test was between 13.6 - 27.9 ml / kg-min with an average 21.03 (+/- 4.2 ml / kg -min) and the maximum oxygen consumption in the lower limbs test was between 18.9 - 36.3 ml / kg-min with an average of 26.3 (+/- 4.6 ml / kg-min).

We found statistically significant differences between the oxygen consumption of upper limbs and lower limbs tests ($p = 0.000$).

3.1. Relationship between the maximum acceptable work time and relative cardiac cost index in tasks performed with upper limbs (U.L).

The acceptable working times vary according to the administered charge. When the workload increases, the maximum acceptable time decreases exponentially.

The equations that explain this behavior showed a high correlation (r) between the variables. A significant difference between men and women was observed, both genders showed a similar pattern in the form of the correlation curve.

Greater engagement in heart rate was evident when the work is done with upper limbs compared to work done with legs and entire body.

Table 1. Relationship between the Maximun acceptable work time and the relative cardiac cost index. Work with upper limbs.

MAWT minutes	rcci			
	50%	40%	30%	20%
MAWT global	19	32	55	96
MAWT male	30	53	93	164
MAWT female	18	31	53	93

The models obtained from the relationship between MAWT, in minutes and RCCI with upper limbs (UL) were exponential with a high negative correlation and are explained by the following formulas:

1. $MAWT\ uper\ limbs = 278.4e^{-0.055rcci} \quad r = 0.92$
2. $MAWT\ uper\ limbs\ male = 501.2e^{-0.056rcci} \quad r = 0.96$
3. $MAWT\ uper\ limbs\ female = 287.1e^{-0.055rcci} \quad r = 0.93$

Limits for physical workload in relation to the exposure time to the load and the relative cardiac cost index were estimated. Table 2.

Table 2. Load limits of physical work suggested for the study population by exposure time based on the upper limbs tests.

Time of work (hours)	RCCI
4	-
2	15
1	30
0.5	40
0.3	50

3.2. *Relationship between maximum acceptable work time and relative cardiac cost index in tasks performed with lower limbs.*

The relationship between MAWT and relative cardiac cost index was obtained by regression analysis. An exponential decrease in MAWT with increasing workload was observed.

In all cases when crossing the variable maximum acceptable work time (MAWT) with the relative cardiac cost index (RCCI), was obtained an exponential model with a negative trend and a high determination coefficient with an statistically significant difference (p = 0.000).

It was observed also a decrease in the maximum acceptable work time as the RCCI is increased as occurred with upper limbs. Table 3.

Table 3. Relationship between MAWT and relative cardiac cost index (RCCI). Lower limbs tests (L.L).

MAWT minutes	RCCI			
	50%	40%	30%	20%
MAWT global	100	1850	330	600
MAWT male	150	250	430	730
MAWT female	90	170	320	615

The following formulas explain the prediction models of acceptable maximum working time, in minutes for lower limbs.

4. $$MAWT\ lower\ limbs = 1980.8e^{-5.921rcci} \quad r = 0.93$$

5. $$MAWT\ lower\ limbs\ male = 2116.2e^{-5.34rcci} \quad r = 0.98$$

6. $$MAWT\ lower\ limbs\ female = 2253.1e^{-6.484rcci} \quad r = 0.95$$

The above findings permit calculate the acceptable maximum working time in hours depending on the RCCI. Table 4.

Table 4. Limits physical workload suggested for the study population for work with lower limbs in relation to the exposure time.

Time of work (hours)	RCCI
12	10
8	24
4	40

4. Discussion

Statistically significant differences between men and women in the RCCI and TAMT were found. Similar results were documented by Wu et al (2002) [9].

The maximum acceptable work times obtained in cycle ergometer for lower limbs and whole body load had similar behavior.

The maximum acceptable working time was much lower when work was performed with upper limbs. The findings that correlate the MAWT with the RCCI, were similar to those proposed by Wu et al (2002) [9] and Rodgers et al (1986) [14]. Table 5.

Table 5. Suggested limits of work load for working times of 12, 8 and 4 hours. Whole body – lower limbs.

	Colombian population		Taiwanese population		European population
Working time - hours	average age 24		average age 26		average age 26
	%VO2max.	RCCI	%VO2max.	RCCI	%VO2max.
12	28,6	10,4	28.5	16	28
8	33	24,6	34	24.5	33
4	46.8	40,4	43.5	39	45

Load limits expressed in terms of VO2 max. and RCCI in the Colombian population were similar those in the study of Taiwanese and European populations [9,13] .

The results showed that the MAWT was significantly correlated with %VO2max and RCCI. Results showed high correlation in each of the variables, with a correlation coefficient over 73%, especially when the RCCI was over 90%. The maximum acceptable work time decreases exponentially in all variables, including gender.

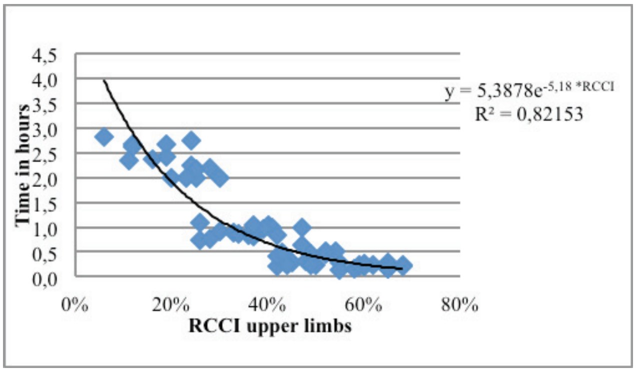

Fig. 1. Relationship between maximum acceptable time and RCCI. Upper limbs tests.

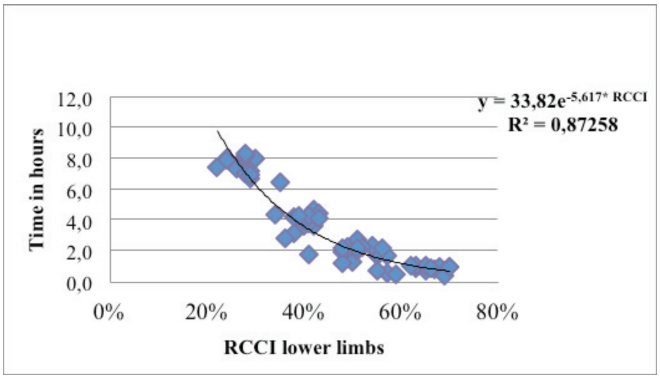

Fig. 2. Relationship between maximum acceptable time and RCCI. Lower limbs tests.

In the review were found no studies that showed the relationship between the %VO2max, the RCCI and MAWT in upper limbs.

This study shows that the maximum acceptable time job for work performed with upper limbs is lower than MAWT obtained for loads in lower limbs, as shown in Table 6 and figures 1 and 2.

Table 6. Relationship between the maximum acceptable time and the RCCI in upper and lower limbs.

MAWT hours	RCCI		
	50%	40%	30%
MAWT Upper limbs	0,25	0,5	1
MAWT Lower limbs	2	4	6

5. Conclusions

Common features of all three models can be summarized as follows:

1) To the extent that the physical workload increases a continuous decrease in MAWT is observed.
2) When there is an increase in the physical workload, the MAWT decreases rapidly and exponentially, aspect to consider in the design of work.
3) MAWT approached zero as the physical workload was heavier and the RCCI was equal or greater than 75%.
4) The MAWT in the upper limbs test is significantly lower than for similar workloads in the lower limbs test.

5) The relative heart rate (RCCI) seems to be a very good estimator of MAWT.

The index of cardiac relative cost seems to be the best indicator to assess the relationship between physical work capacity, the workload and maximum acceptable working time with upper and lower limbs due to its low cost, simplicity and sensitivity for measurement.

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