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Technical Report N° 20

DEVELOPMENT OF A SIMPLIFIED TEST TO DETERMINE INDIVIDUAL APTITUDE FOR PHYSICAL EFFORT AND EXPOSURE TO HEAT

Source : Ergonomic Team of the Luxembourg Steel Industry
Project N° 2

Author : Dr R. FOEHR

Reference period : 1.7.1971 - 30.6.1974

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1. INTRODUCTION

A few years ago we developed a method of measuring workloads and heat loads using continuous recording of cardiac frequency (Vogt and Co-workers, 1970).

Our method is based on quantitative physiological relationships, established in the laboratory, between metabolic and thermal stresses on the one hand and cardiac strain on the other. This was a practical application of fundamental research in the area of industrial physiology.

The basic concept arrived at as the conclusion of this fundamental research was the possibility of dividing the overall tachycardiac reaction into two components: one of them corresponds to the oxygen transfer required by muscular work, and the other to heat transfer, firstly by reason of the increased production of metabolic heat and secondly because of the reduction in the temperature gradient between the centre of the body and the skin (Vogt, 1966). The second component is closely linked to the level of the central temperature. The cardiac frequency level associated with the level of the central temperature can be estimated, preferably during a rest period of 10 minutes in which the mean cardiac frequency corresponds to the desired cardiac frequency level. If the rest period is shorter than 10 minutes, the value for the fourth minute of recovery gives an adequate approximation of the same cardiac frequency level (Vogt, 1967).

The metabolic and thermal stresses are determined in two stages. In the first stage the worker carries out an effort test in a climatic chamber for calibration purposes. In the second stage, the worker is examined for the entire duration of the working shift. Figure 1 outlines the procedure used.

Physiological calibration of the worker is effected in the climatic chamber. Here the worker undergoes a standard effort test for metabolic and thermal stress. The circulatory strain is estimated by continuous recording of the cardiac frequency, broken down into its two components. The relationship between the metabolic and thermal stress and the imposed strains enables the metabolic cardiac reactivity and the thermal cardiac reactivity to be evaluated (see figure 1).

The worker then performs his normal job in the factory. Troughout the working shift his cardiac frequency is recorded continuously. A mobile industrial physiology unit (Foehr, 1967) enables recordings to be made at every workplace in the factory. The circulatory strain measured in this way is broken down into its two components; applying the cardiac reactivities determined previously, the metabolic and thermal stresses of the workplace under examination are then evaluated. This method has since been validated for a wide range of work situations presenting frequent and broad fluctuations in energy expenditure and external heat load (Vogt and co-Workers, 1972).

2. PURPOSE OF THE RESEARCH

This working method has two major drawbacks at the calibration stage:

a) a financial drawback, since its application requires the use of a climatic chamber enabling an exogenous heat load to be imposed, and an ergometric bicycle enabling exclusively positive work to be performed with an intensity which is easy to check;

b) a problem of duration since the calibration extends over a period of 105 minutes. The aim of this calibration is on the one hand to determine a motor cardiac reactivity calculated during application of a positive motor stress and on the other to define a thermal cardiac reactivity which is calculated during the application of a mixed - i.e. both endogenous and exogenous - thermal stress.

In the course of this study we explored the possibility of effecting the evaluation of the motor and thermal cardiac reactivities by means of a different physical activity carried out in a neutral thermal environment. The physical work used was a step-test combining by its very nature positive work (climbing onto the stool) and negative work (stepping down from the stool). The neutral environment was used by analogy with the environment in a medical consulting room. The imposed thermal stress was therefore of purely endogenous origin. With this aim in mind, it was necessary to establish that:

a) the individual cardiac reactivity measured during a certain type of muscular activity (e.g. pedalling) is equivalent to the individual cardiac reactivity measured during a different type of exercise (such as a step-test);

b) the individual cardiac reactivity to a purely endogenous stress is equivalent to the individual cardiac reactivity to a mixed thermal stress (endogenous of exogenous);

c) a valid estimate of these individual cardiac reactivities can be made under convenient conditions in regard to the duration and intensity of the stresses.

3. METHOD

The reference test used to measure individual cardiac reactitivy to effort and thermal stress is that described in the original article defining the measuring method. The subject is exposed simultaneously in a climatic chamber to a motor stress and a mixed thermal stress.

The motor stress is characterized by:

- 10 minutes rest;
- 30 minutes pedalling at 50 watts;
- 10 minutes rest;
- 20 minutes pedalling at 75 watts;
- 10 minutes rest;
- 15 minutes pedalling at 100 watts;
- 10 minutes rest.

The thermal stress is mixed because it comprises an endogenous thermal load resulting from the muscular activity described above and an exogenous thermal load, since this effort test is conducted at an air temperature of 40°C, $T_g=T_a$, T_h = 30°C, V_a = 0.3 m/sec.

During this test which lasts for 105 minutes, the subject performs work of 27,540 kJ, the evaporation required to maintain homeothermy being 390 kcal.

We compared with this reference test four effort tests consisting of step-tests whose structures are outlined in Figure 2. Each effort test comprises three periods of muscular exercise at successively increasing powers, interspersed with periods of rest in a seated posture. The muscular exercise periods last for 5, 10, 15 or 20 minutes. Considering only the positive work done during the step-tests (climbing onto a stool), the powers were 45, 67.5 and 90 watts. The respective durations of these four effort tests are 55, 67.5, 85 and 100 minutes. The total positive work performed was 6,300, 12,600, 18,900 and 25,200 kJ respectively. These step-tests were conducted in a medical consulting room with the following ambient thermal conditions: T_a = 22°C; $T_g = T_a$; T_h = 15°C; V_a = 0.3 m/s. The corresponding evaporation requirement is 5, 50, 95 and 140 kcal.

During all these experiments, the cardiac frequency was continuously measured by telemetry.

The reference effort test and experimental effort tests (a total of 5 experiments per subject) were carried out in succession, but on different days on a group of 12 subjects. Because of a number of unforeseen incidents all the results of the experiments could not be fully analysed and processed.

4. RESULTS

4.1 Expression of the results

The ten minute rest periods between the work periods in each experiment enable - in their second half - the cardiac frequency level determined by the thermal state of the organism to be estimated (Vogt and co-workers, 1971). The average cardiac frequency level observed in the rest period preceding the first effort test corresponds to the initial cardiac frequency. The sum of the differences between the observed cardiac frequency values and this initial cardiac frequency constitutes the total cardiac extra-pulsations (EPCTOT). Linear interpolation between the cardiac frequency levels in successive rest periods enables the EPCTOT to be broken down into two components:

a) cardiac extra-pulsations comprised between the initial cardiac frequency and this broken line of interpolation depending on the thermophoric function of the cardiac output: we define these as thermal cardiac extra-pulsations (EPCT);

b) cardiac extra-pulsations obtained by differentiation between the EPCTOT and EPCT depend on the oxyphoric function of the cardiac output: we refer to these as motor cardiac extra-pulsations (EPCM).

The relationship between the EPCT and the evaporation required to maintain homeothermy is an indicator of individual reactivity to an endogenous or mixed thermal load. Similarly the relationship between the EPCM and the total mechanical work performed is an expression of individual reactivity to muscular effort. The two relationships express thermal cardiac reactivity (RCT) and motor reactivity (RCM) respectively. The results will be expressed either in EPCT and EPCM or in RCT and RCM.

4.2 Analysis of initial cardiac frequency

Table 1 shows the initial cardiac frequencies observed during the first seated rest periods lasting for 10 minutes. The first column shows the cardiac frequency values observed during the step-tests. The intra- and inter-individual means, and the corresponding standard deviations are grouped in the two last columns and two last lines respectively.

There is clearly a very wide intra- and inter-individual dispersion. Variance analysis of all the results shows highly significant inter-individual differences. Overall, the initial cardiac frequencies observed during the five laboratory tests do not differ between themselves. On the other hand, comparing them two by two, it appears that the initial cardiac frequency observed during the experiment in the climatic chamber is significantly higher than the initial cardiac frequencies observed during ST-10, ST-15 and ST-20. This difference is due, in part at least, to the fact that the first rest period of the climatic chamber experiment was conducted in a warm atmosphere whereas the initial rest periods of the step-tests all took place in a neutral thermal environment.

4.3 Analysis of the motor component

The main results are shown in Table 2: the two left-hand columns represent the EPCM and RCM observed and calculated during the reference experiments in a climatic chamber; the four next columns show the EPCM observed in the four step-tests and the four last columns represent the correlation coefficient, the slope, the original ordinate and the statistical significance of the relationship between the observed EPCM and the workloads imposed (in kJ) during the four step-tests. The next to last line of the table shows the inter-individual mean of the different measured parameters and the regression calculated on these mean values. The standard deviations of the last line indicate the inter-individual dispersion.

Figure 3 represents the relationship between the inter-individual means of the EPCM (values in heavy type in Table 2) and the corresponding motor stresses imposed in the four step-tests. The point representing the reference experiment conducted in the climatic chamber is also shown. This point is not located on the straight regression line calculated solely for the four step-tests. In the calculation of physical work performed during the step-tests we allowed only for positive work (climbing onto the stool) and not for negative work (stepping down from the stool). As the physical work performed on the ergometric bicycle is solely positive, the relationship between the physiological strain and the physical work calculated in this way clearly cannot be the same. In fact the negative work which constitutes a substantial part of the step-test is at the origin of a physiological strain but it is disregarded in the calculation of physical work effected during this type of experiment.

Table 2 shows that for all the test subjects, the EPCM obtained in the step-tests are closely linked to the corresponding workloads. With one exception (Sg) the correlations are always statistically significant. For each subject the slopes b for these regressions represent the mean RCM for all four step-tests. There are very wide inter-individual differences. These individual values are closely linked with the individual RCM values calculated in the climatic chamber:

$$RCM(CC) = -0.015 + \overline{0.867}\ RCM\ (\overline{ST}) \qquad (1)$$
$$r = 0.832 \text{ for } 9 \text{ dl } (P\ 0.01)$$

where

$RCM(CC)$ = motor cardiac reactivity observed in the climatic chamber;

$\overline{RCM}(\overline{ST})$ = slope b of individual correlations shown in Table 2.

<u>Individual aptitude for physical effort of the pedalling type can therefore be predicted from a series of 4 effort tests of the step-test type</u>.

In order to determine the minimum duration of a step-test enabling an adequate estimate to be made of individual cardiac reactivity to effort, we calculated for each step-test the corresponding RCM. This is obtained from the relationship between the EPCM and work performed (in kJ). Figure 4 shows the relationships between the step-test RCMs and the reference RCMs calculated for the climatic chamber. Each point shown on these figures represents an individual value. All the available individual values are shown on these figures. The correlations are highly significant. Even the shortest step-test allows a good estimate of individual reactivity calculated during work on an ergometric bicycle.

$$RCM(CC) = 0.013 + 0.591\ RCM(ST\text{-}5) \qquad (2)$$
$$r = 0.827 \text{ for 9 dl } (P\ 0.01)$$
$$RCM(CC) = 0.002 + 0.674\ RCM\ (ST\text{-}10) \qquad (3)$$
$$r = 0.823 \text{ for 9 dl } (P\ 0.01)$$
$$RCM(CC) = 0.006 + 0.581\ RCM\ (ST\text{-}15) \qquad (4)$$
$$r = 0.779 \text{ for 9 dl } (P\ 0.01)$$
$$RCM(CC) = 0.002 + 0.616\ RCM(ST\text{-}20) \qquad (5)$$
$$r = 0.898 \text{ for 8 dl } (P\ 0.001)$$

where RCM(CC) = motor cardiac reactivity observed in the climatic chamber;

RCM(ST) = motor cardiac reactivity observed during the step-test.

4.4. Analysis of the thermal component

The main results are shown in Table 3: the two left-hand columns represent the EPCT and RCT observed and calculated during the reference experiments in the climatic chamber; the four following columns represent the correlation coefficient, the slope, the original ordinate and the statistical significance of the relationship between the observed EPCT and the required evaporations imposed (in kcal) during the four step-tests. The next to last line of the table represents the inter-individual mean of the different parameters measured and the regression calculated on these mean values. The standard deviations of the last line correspond to the inter-individual dispersions.

Figure 5 represents the relationship between the inter-individual means for the EPCT (values in heavy type in Table 3) and the corresponding thermal stresses imposed during the four step-tests. On average, for all twelve subjects the relationship represented in Figure 5 is highly significant. On this figure we have also shown the point corresponding to the reference experiment conducted in the climatic chamber. This point is not situated on the extension of the regression calculated for the four points of the step-test.

Table 3 shows that the EPCT for the step-tests are linked to the endogenous thermal loads for 8 subjects out of twelve. For the subjects presenting a significant or indicative correlation in Table 3, the slope of this relati nship is representative of the individual reactivity to an edogenous thermal stress. These reactivities vary widely from one individual to another. The values for the $\overline{RCT}(\overline{ST})$ determined in four step-tests are significantly correlated to the individual RCT values determined in the climatic chamber.

$$RCT(CC) = 0.706 + 0.345\ \overline{RCT}(\overline{ST}) \qquad (6)$$

$$r = 0.792 \text{ for 5 dl } (P\ 0.01)$$

where

RCT(CC) = thermal cardiac reactivity observed in the climatic chamber;

$\overline{RCT}(\overline{ST})$ = slopes b for individual correlations shown in Table 2

<u>The individual aptitude to undergo a mixed thermal load may therefore be predicted in the case of 8 subjects out of 12 from a set of experiments during which we imposed exclusively endogenous thermal stresses</u>.

The fact that 4 subjects out of 12 show no correlation between the EPCT values for the step-tests and the corresponding required evaporations may be due to the impossibility of estimating RCT from very short step-tests. The random dispersion of the EPCT values in short step-tests would be so wide that the measured value is not representative of the thermal load undergone.

That is the reason why for each step-test duration we sought the relationship between the RCT calculated from observations in the climatic chamber and that calculated for each step-test. The RCT for each step-test was calculated by establishing the relationship between the EPCT values and the required evaporation expressed in kcal. Figure 6 shows the relationships between the RCT values for the step-tests and those for the experiment conducted in the climatic chamber.

The RCT values determined from the 5 to 10 minute step-tests show no correlation with those determined during the reference tests in the climatic chamber. The RCT values determined during the 15 minute step-tests are linked indicatively to the reference RCT values. This relationship is as follows:

$$\begin{aligned} RCT(CC) &= 0.49 + 0.259\ RCT(ST\text{-}15) \qquad (7) \\ r &= 0.584 \text{ for } 9 \text{ dl } (P\ 0.1) \end{aligned}$$

Only the relationship linking the RCT values for the 20 minute step-test to the reference RCT values is:

$$\begin{aligned} RCT(CC) &= 0.14 + 0.412\ RCT\ (ST\text{-}20) \qquad (8) \\ r &= 0.851 \text{ for } 8 \text{ dl } (P\ 0.01) \end{aligned}$$

where RCT(CC) = thermal cardiac reactivity determined in the climatic chamber during exposure to a mixed thermal stress;

RCT(ST) = thermal cardiac reactivity determined in a step-test.

5. DISCUSSION

A step-test performed in a neutral thermal environment enables individual cardiac reactivity to physical effort and individual cardiac reactivity to a mixed thermal stress to be estimated. Individual reactivity to physical effort can be estimated from a step-test comprising three 5 minute working phases. Individual reactivity on exposure to a mixed thermal stress can only be validly estimated from a step-test comprising three working phases of at least 15 minutes each. A step-test comprising three working phases of 20 minutes enables a very good estimate to be obtained of individual reactivity to a mixed thermal stress.

5.1 Validity of the estimate of cardiac reactivity to physical effort

Cardiac reactivity to physical effort is represented by the RCM. This corresponds to the relationship between the EPCM and the motor stress to which the subject is exposed (CM). In our experiment the reference corresponds to work on an ergometric bicycle. The recommended test uses a step-test as the physical effort factor.

Figure 4 shows that the reference RCM values estimated during work on an ergometric bicycle are closely linked with the RCM values estimated during a step-test. Even the shortest step-test enables the reference RCM to be predicted. Equations 3, 4, 5 and 6 correspond to the straight lines shown on Figure 4. The original ordinates do not differ significantly from zero for ST-10, ST-15 and ST-20.On the other hand the RCM value for ST-5 is not directly proportional to the reference RCM as the original ordinate differs significantly from zero.

Looking at the ST-10, ST-15 and ST-20 values, two conclusions can be drawn. The first is that the reference RCM is always lower than that determined in the step-tests. This observation has already been discussed in section 3.3. For the same positive physical work, the EPCM values are higher during a step-test than for pedalling on an ergometric bicycle. The ratio between the two is about 1.5. This difference is mainly due to the fact that in the step-test the individual performs a very substantial negative physical work. The latter which imposes a physiological strain, is not taken into account in calculating the physical work performed. Our results show that the physiological strain is increased by about 50 per cent.

The second conclusion concerns the estimation of motor stresses. Based on the EPCM values and one RCM we estimate a motor stress. All other factors being equal regarding the EPCM, the motor stress is solely dependent on the RCM. The fact that the correlations between the reference RCM values and the RCM values for ST-10, ST-15 and ST-20 have an ordinate which is originally zero shows that for all the subjects:

$$RCM(CC) = s.RCM(ST)$$

now $$RCM(CC) = EPCM(CC)/CM(CC)$$

and $$RCM(ST) = EPCM(ST)/CM(ST)$$

From these three equations we derive the following equation:

$$CM(ST) = \frac{EPCM(ST)}{EPCM(CC)} .a.\ CM\ (CC)$$

This equation can be written for any combination of work, in particular for work of the step-test type (used for calibration purposes in this case) and for work in the factory :

$$CM(U) = \frac{EPCM(U)}{EPCM(ST)} .x.\ CM\ (ST)$$

where CM(U) = motor stresses imposed during work in the factory;
EPCM(U) = motor cardiac extra-pulsations observed in the factory;
x = proportionality coefficient.

The EPCM(U) and EPCM(ST) values are both known with an instrumental error of approximately 1 per cent. Consequently for all test subjects CM(U) is in a constant relationship with CM(ST). It follows that the motor stress estimated for a workplace only represents an (unknown) fraction of the physical work done in a step-test. This fraction is the same for all subjects. The equivalent motor stress estimated for a workplace is consequently free from inter-individual differences. This latter characteristic is essential for a motor stress.

5.2 Validity of the estimate of cardiac reactivity to a thermal stress

During the reference test, the subjects are exposed to a mixed thermal stress (endogenous and exogenous). The proposed test only uses an endogenous thermal stress. The results show that individual cardiac reactivity to an endogenous thermal stress enables the individual cardiac reactivity to a mixed thermal stress to be predicted. A good estimate of this latter parameter implies a minimum required evaporation of about 100 kcal (ST-15), preferably approaching 150 kcal (ST-20). If the required evaporation is too low, the thermolysis machanisms will not be sufficiently stressed and it will therefore not be possible to determine this individual reactivity accurately.

The thermal stress is either mixed or purely endogenous. In both cases the energy metabolism plays a quantitative part in the thermal stress. It is consequently proportional to the motor stress. If the breakdown of the EPCTOT values led to EPCM and EPCT values in an identical ratio for all the test subjects, there would inevitably be a close relationship between the RCT(CC) and RCT(ST) values. If this were the case, we should obtain for all the subjects:

$$EPCT(ST) = c.\ EPCM(ST) \qquad (7)$$

and

$$CT(ST) = d.\ CM(ST) \qquad (8)$$

The relationship between these two equations would give:

$$\frac{EPCT(ST)}{CT(ST)} = \frac{c}{d}\ \frac{EPCM(ST)}{CM(ST}$$

Moreover, since $RCM(ST) = \frac{EPCM(ST)}{CM(ST)}$ and $RCT(ST) = \frac{EPCT(ST)}{CT(ST)}$

we should obtain $RCT(ST) = \frac{c}{d}\ RCM(ST)$

Since the RCM(ST) and RCM(CC) values are closely linked (see section 3.3) it is apparent that RCT(ST) and RTC(CC) would also be closely linked if equation (7) were exact. We therefore analysed the inter-individual differences for the EPCM and EPCT values: as there is no mathematical relationship between the two parameters, equation (7) is unfounded. Consequently this absence of a direct relationship reflects independence between the individual cardiac reactivity to physical work and cardiac reactivity to a thermal stress and not merely some irregularity in the method of processing the results. The independence of these two individual reactivities is confirmed by all five experiments which we conducted. The relationships between the RCT(ST) and RTC(CC) values for the ST-15 and ST-20 tests are not artificial (due to relationships between the RCM(ST) and RCM(CC)) and reflect a link existing between the individual reactivities to an exclusively endogenous thermal stress and individual reactivities to a mixed thermal stress.

The ordinates at the origin of these two regressions do not differ statistically from zero. The RTC(ST) values are therefore directly proportional to the RTC(CC) values. The same reasoning followed above for the RCM values (see section 4.1) can be applied to the RCT values and to the estimate of thermal stresses. It follows that the estimated thermal stress at a workplace only represents an (unknown) fraction of the heat load undergone in the step-test. This fraction is the same for all test subjects. The equivalent thermal stress estimated for a workplace is therefore free from inter-individual differences.

For a given thermal stress, the EPCT values are much higher when the stress is purely endogenous (step-test) than when it is mixed (climatic chamber). The regression slopes linking the RTC(CC) values to the RCT(ST) values, and Figure 5, confirm this. The thermal stress criterion adopted in this case was the required evaporation. The EPCT values are representative of internal heat transfer. The required evaporation is representative of external heat transfer. For a given thermal stress, depending on whether it is mainly endogenous or exogenous, it is logical to observe higher EPCTs the greater the endogenous fraction of the thermal stress. In the case of thermal stress, the proposed measuring method consequently leads to a real equivalent thermal stress. The equivalence is assessed on the basis of the cardiac effort imposed by the heat load. This effort depends on the respective proportions of the endogenous and exogenous stresses.

5.3 Dispersion of the results

The dispersion of the results is generally very wide. Correlations are never very close when we consider individual values. The very wide dispersion observed is mainly due to the experimental conditions. As the method has to be used in an industrial environment it was desirable to validate it under industrial conditions.

It is very difficult to determine the mode of life of workers who perform their habitual activities: type of food eaten, drugs, alcohol, duration of sleep, other work etc... Despite the poor control of the initial physiological conditions, the results show that the estimate of individual reactivity remains valid. The very wide dispersion is due primarily to physiological fluctuations of the cardiac frequency.

The dispersion of the points in Figures 4 and 6 indicates the accuracy of determination of the RCM and RCT values. The mean residual standard deviation is 0.010 c/kgm for the step-test RCMs. For the RCTs in the twenty minute step-test (most significant correlation) the residual standard deviation is equal to 1.16 c/kcal. Allowing for a mean RCM of 0.079 c/kgm and a mean RCT of 4.17 c/kcal, it is apparent that these parameters show a variation coefficient of 0.12 for RCM and 0.27 for RCT.

The main coefficient of variation for the RCM and RCT values derives solely from the physiological fluctuations in EPCM and EPCT, since the motor and thermal stresses were stringently controlled and the instrumental error on the EPCM and EPCT is approximately 1 per cent. During the use of RCM and RCT in the industrial environment, the estimates of equivalent motor and thermal stresses will be imprecise because of the physiological fluctuations in the EPCM and EPCT. To reduce the error on the EPCM and EPCT measured in the factory, it is desirable to increase the number of measurements.

Repetition of the EPCM and EPCT measurements in the industrial environment enables the mean EPCM and EPCT values at the workplace to be calculated. The dispersion of these mean values is lower the greater the number of measurements. If it is hoped to reduce the variation coefficient of this distribution of mean values to 0.10 it appears that for the motor stress, $(0.12/0.10)^2$ i.e. 1/4 measurements will be sufficient, and for the thermal stress $(0.27/0.10)^2$ or 7.3 measurements. To obtain a precise estimate (with a ten per cent margin) of the motor stress imposed by a workplace 2 continuous 8 hour recordings will be necessary. **To obtain a precise estimate (with a ten per cent margin) of the thermal stress imposed by a workplace 8 continous 8 hour recordings will be necessary.**

6. CONCLUSIONS

In conclusion these experiments show that:

- it is possible to make a valid estimate of individual cardiac reactivity to a certain type of work on the basis of observations of another type of work;

- individual reactivity to a mixed thermal stress (endogenous and exogenous) can be estimated from observation of individual reactions to an exclusively endogenous thermal stress;

- a minimum motor stress of 12,600 kJ is needed to estimate accurately the individual cardiac reactivity to a muscular exercise;

- a minimum thermal stress equivalent to 150 kcal required evaporation is desirable to estimate validly an individual cardiac reactivity to a thermal stress;

- in view of the impossibility of imposing stringent conditions concerning food intake, tobacco consumption and rest on workers in the industrial environment, at least two recordings of complete shifts must be taken to obtain an estimate with a 10 per cent accuracy margin of equivalent motor stress; at least eight recordings must be taken for complete shifts to obtain an estimate with a ten per cent accuracy margin of equivalent thermal stress.

The method proposed in this paper can be applied easely. There is no need for a climatic chamber equipped with an ergometric bicycle to effect an individual calibration of motor and thermal cardiac reactivities. It is sufficient to carry out a step-test in a neutral environment. Provided that the calibration is always conducted under identical conditions, application of this method enables motor and thermal stresses to be estimated without inter-individual fluctuations. Determination of these equivalent stresses enables the stresses undergone at different workplaces to be compared with those undergone at a single workplace before and after ergonomic intervention.

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	CLIMATIC CHAMBER	ST - 5	ST - 10	ST - 15	ST - 20	mean	σ
S_1	87,86	81,57	86,00	84,29	84,86	84,92	2,31
S_2	96,71	79,14	83,71	73,00	79,71	82,45	8,84
S_3	79,86	79,57	75,29	68,14	71,43	74,86	5,11
S_4	75,00	82,86	80,86	73,14	72,86	76,94	4,62
S_5	75,00	65,57	66,43	66,57	64,86	67,69	4,15
S_6	—	82,29	72,50	81,43	81,43	79,41	4,62
S_7	69,71	71,57	71,71	—	74,57	71,89	4,02
S_8	86,57	84,14	70,00	77,00	—	79,43	7,48
S_9	82,29	93,43	76,00	78,43	88,86	83,80	7,25
S_{10}	82,86	72,00	61,86	83,86	78,57	75,83	9,10
S_{11}	83,00	81,14	86,57	78,14	79,71	81,71	3,25
S_{12}	88,00	87,14	88,17	87,57	83,43	86,86	1,96
Mean	82,44	80,03	76,59	77,42	78,20	79,08	7,42
σ	7,49	7,44	8,51	6,72	6,82	—	—

Table 1: Mean cardiac frequencies in 10 minute initial rest period (S1 = subject 1...)

	CLIMATIC CHAMBER		STEP TESTS							
	EPCM	RCM	EPCM ST-5	EPCM ST-10	EPCM ST-15	EPCM ST-20	r	b	a	Signif.
Work (KJ)	27540	—	6 300	12 600	18 900	25 200	—	—	—	—
S_1	1160	0,042	345	714	1015	1196	0,989	0,0453	104,03	S.
S_2	1385	0,050	467	989	1578	2159	0,999	0,0899	-117,99	HS.
S_3	1658	0,060	405	825	1525	2020	0,996	0,0880	-192,41	S.
S_4	1234	0,045	289	745	1107	1503	0,999	0,0636	- 89,91	HS.
S_5	2136	0,076	612	1256	1963	2751	0,999	0,1131	-135,35	HS.
S_6	—	—	443	932	1519	2174	0,998	0,0917	-177,91	S.
S_7	1174	0,043	363	813	—	1734	0,999	0,0726	- 97,22	S.
S_8	2122	0,121	626	1353	2151	—	0,999	0,1210	-148,31	HS
S_9	1380	0,050	587	1133	2008	1932	0,933	0,0779	187,60	I.
S_{10}	1395	0,051	461	1098	1560	2093	0,998	0,0850	- 36,38	S.
S_{11}	1103	0,040	396	827	1336	1708	0,998	0,0706	- 44,41	S.
S_{12}	2022	0,073	582	1191	1840	2701	0,996	0,1112	-172,9	S.
Mean	1524	0,059	465	990	1588	1997	0,997	0,0824	-38,43	S.
σ	396	0,023	113	213	350	466	—	—	—	—

Table 2: Motor cardiac extrapulsations (EPCM) and motor cardiac reactivity (RCM) observed and calculated for step-tests (ST), and for experiments in a climatic chamber. The four last columns show the correlation coefficients "r", the slopes "b", the original ordinates "a" and the statistical significance of the regressions linking the EPCM and work in kJ for the 4 step-tests.

	CLIMATIC CHAMBER		STEP TESTS							
	EPCT	RCT	EPCT ST-5	EPCT ST-10	EPCT ST-15	EPCT ST-20	r	b	a	Signif.
E_r (kcal)	391	—	5	50	95	140	—	—	—	—
S_1	242	0,619	37	52	151	90	0,651	—	—	N.S
S_2	359	0,918	136	146	497	564	0,929	71,63	3,63	I.
S_3	608	1,555	122	224	629	623	0,928	90,95	4,241	I.
S_4	294	0,752	99	124	155	226	0,966	84,30	0,917	S.
S_5	1007	2,575	123	267	359	843	0,930	33,27	5,013	I.
S_6	—	—	237	447	679	961	0,997	191,61	5,35	S.
S_7	762	1,949	170	192	—	279	0,988	159,41	0,83	I.
S_8	862	2,205	189	572	177	—	-0,014	—	—	N.S
S_9	500	1,278	160	652	539	529	0,606	—	—	N.S.
S_{10}	475	1,215	142	215	225	276	0,965	147,6	0,92	S.
S_{11}	1573	4,023	154	129	848	1081	0,929	- 12,26	7,77	I.
S_{12}	219	0,560	206	144	381	267	0,532	—	—	N.S
Mean	627	1,604	147,9	263,6	421	521,7	0,999	129,0	2,79	H.S.
σ	406	1,038	51,9	190,5	236	328,5	—	—	—	—

Table 3: Thermal cardiac extrapulsations (EPCT) and thermal cardiac reactivity (RCT) observed and calculated for experiments in a climatic chamber and for step-tests (ST). The four last columns show the correlation coefficients "r", the slopes "b" the original ordinates "a" and the statistical significance of the regressions linking the EPCT and required evaporation values (E_r) in kcal for the 4 step-tests.

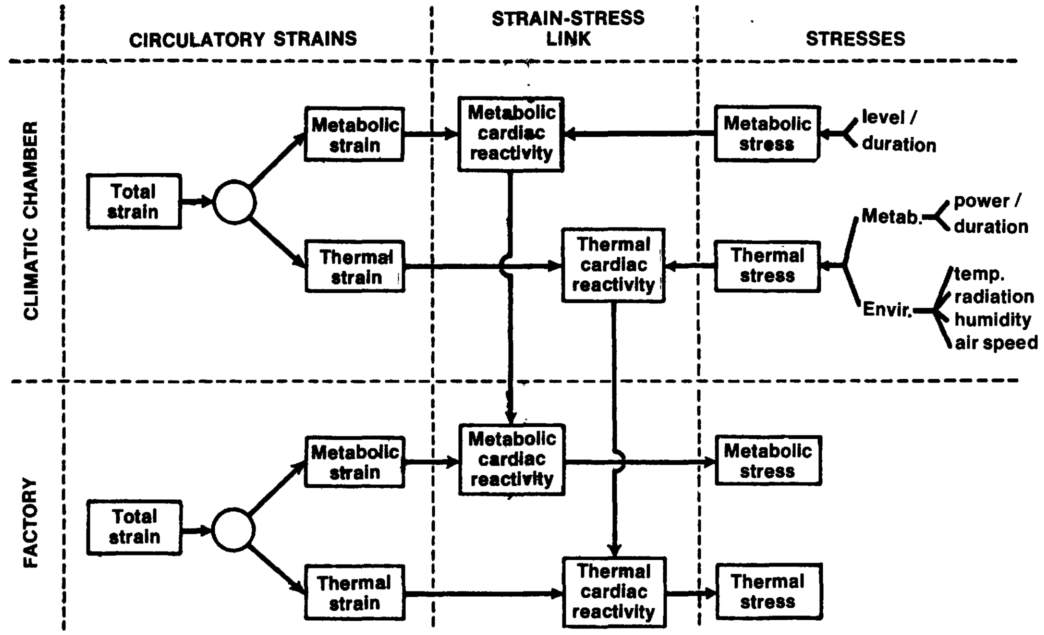

Fig. 1 – Schematic diagram of the method
Arrows indicate operations to be effected successively

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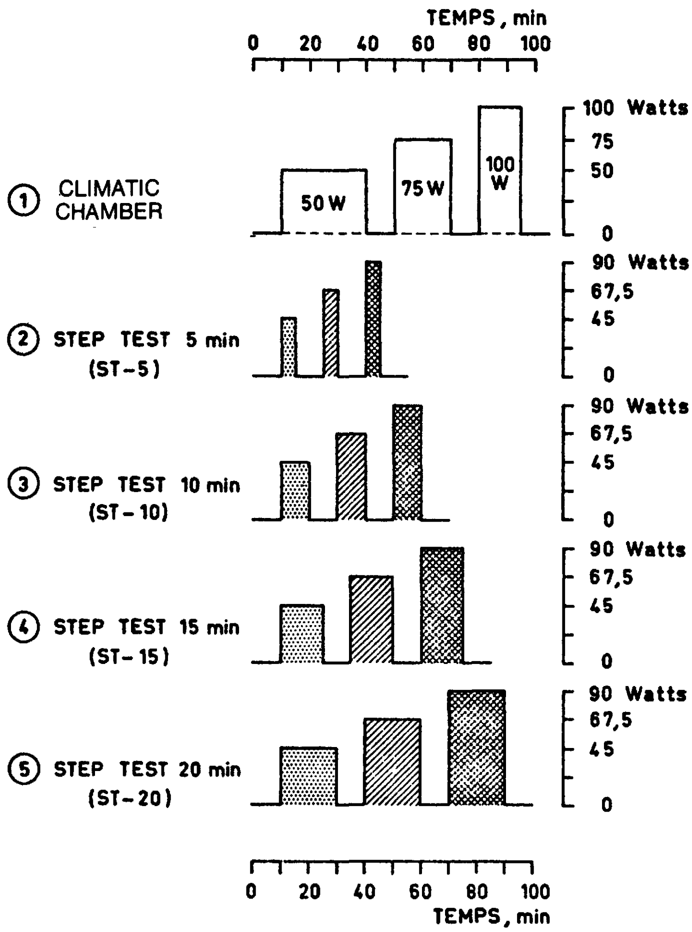

Figure 2: Structure of experiments

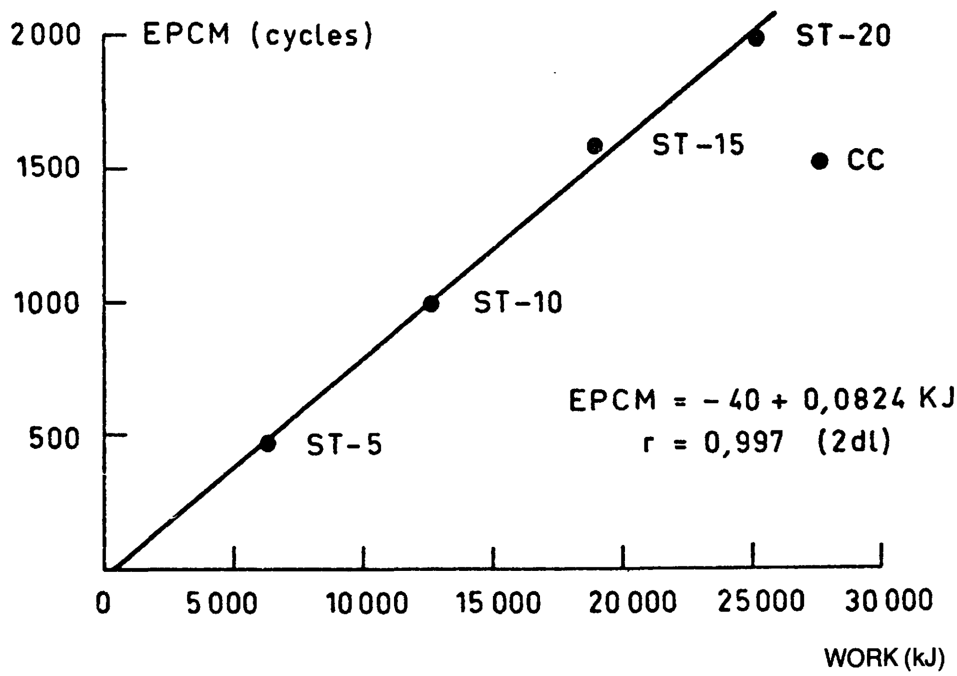

Figure 3: Relationships between inter-individual means for motor cardiac extrapulsations (EPCM) and work quantities (in kJ) for all 4 step-tests. Point "CC" corresponds to the experiment in a climatic chamber.

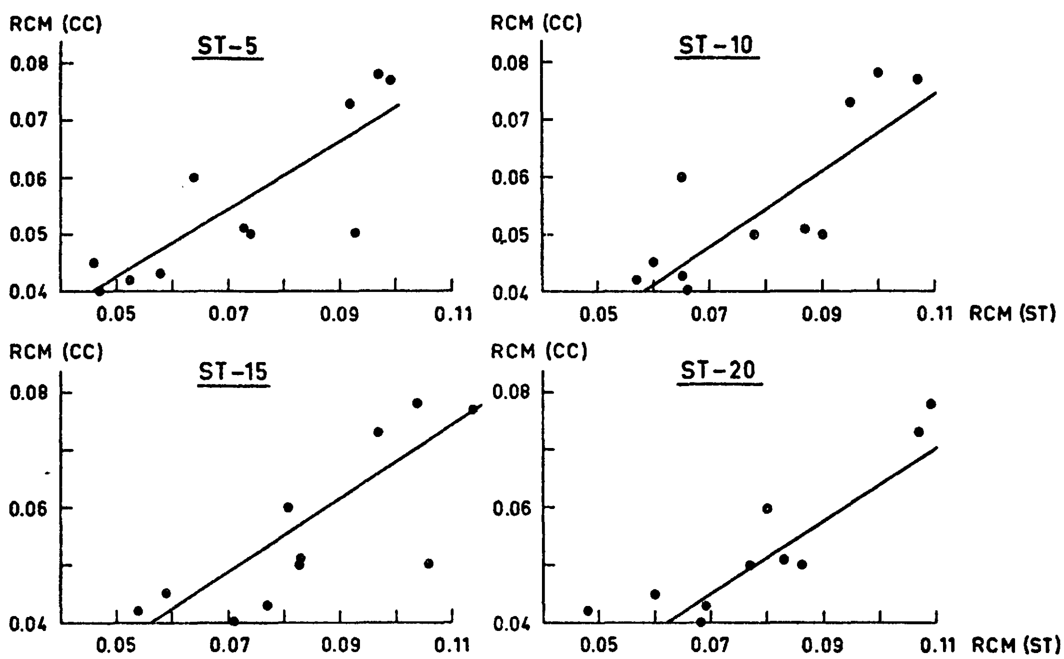

Figure 4: Relationships between individual motor cardiac reactivity values for the experiment in the climatic chamber (RCM(CC)) and in the step-tests (RCM(ST)).

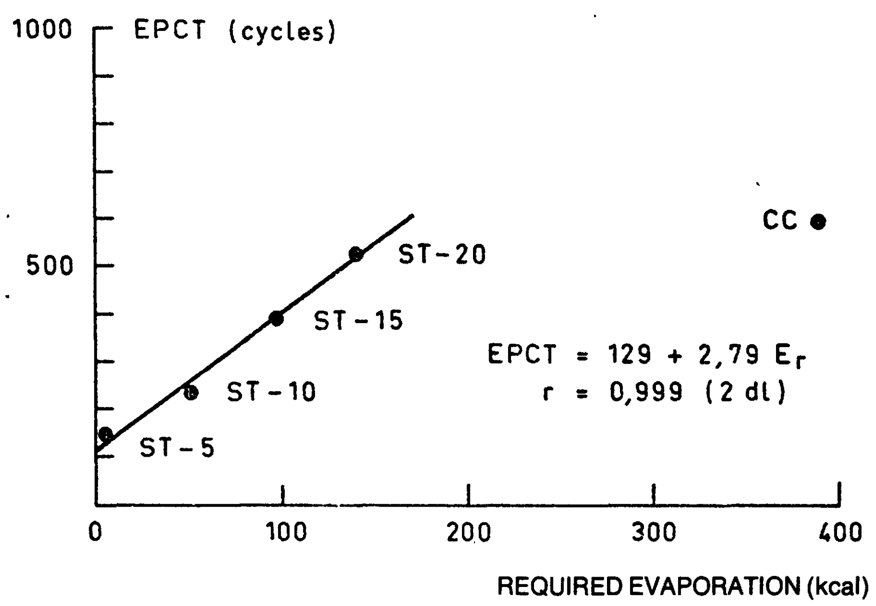

Figure 5: Relationships between inter-individual means for thermal cardiac extrapulsations (EPCT) and required evaporation values (in kcal) for all 4 step-tests. Point "CC" corresponds to the experiment in the climatic chamber

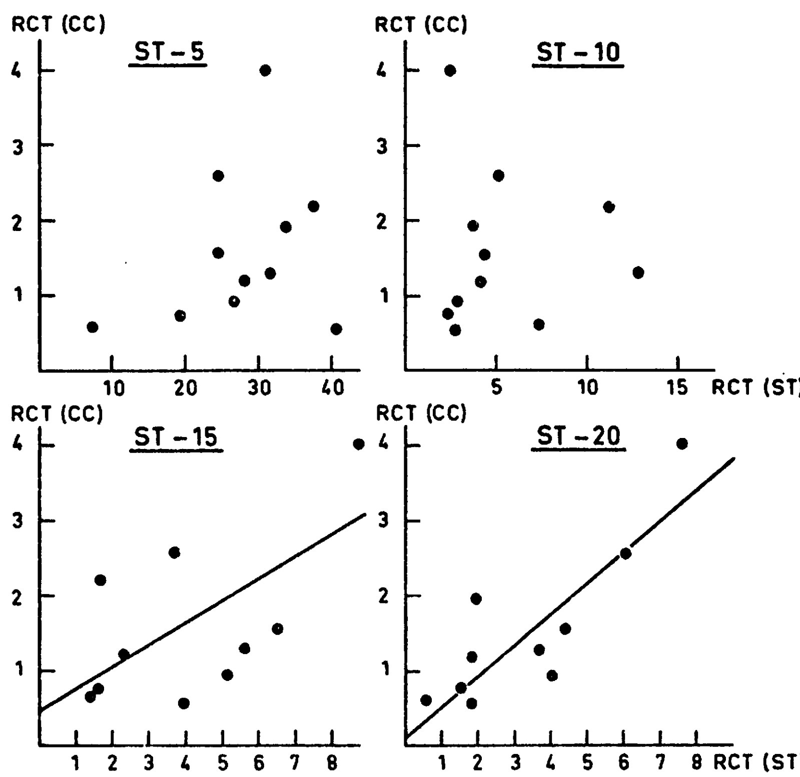

Figure 6: Relationships between individual values of thermal cardiac reactivities in the experiment in the climatic chamber (RCT(CC)) and in the step-tests (RCT(ST)).