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PERCEIVED EXERTION AS AN INDICATOR OF SOMATIC STRESS

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ABSTRACT. The study shows the applicability of perceived exertion as a complement to physiological stress indicators. A simple scale for ratings of perceived exertion has been constructed. Patients with vaso-regulatory asthenia give lower rating in relation to heart rate than a healthy control group. In patients with coronary heart disease this relation is the opposite. Ratings of exertion are helpful when we want to know when to interrupt a worktest. Patients are advised to practise their own ratings so that they learn to modify exercise intensity to a level that is just right for them. A work test is described with a feedback system to guide the test course. A new walktest is also described, which demands no special equipment. In the test the subject has to walk a given distance and the time spent is, together with the heart rate, used to obtain a measurement of the physical fitness.

Psychological aspects of work physiology and clinical physiology include many problems of interest in rehabilitation, sports medicine and physical education, ergonomics and human factors engineering. There are still many jobs that are physically very stressing and among causes of dissatisfaction at various places of work, physical work load is one of the more significant ones. Decrease of the physical working capacity of an individual causes many psychological problems and is one of the more important reasons why a person seeks medical aid. The decrease of the physical working capacity as perceived by the subject, does not, however, seem to grow linearly with the decrease as measured by the physical laboratory tests. And when the physical work load is increased, the subjective force or the perceived exertion does not grow linearly with the physical load. Since man reacts to the world as he perceives it and not as it "really is", it is important to know more about the relation between objective and subjective measurements of physical stress. Also in constructing a training program and making exercise prescriptions for different individuals, many psychological aspects come into play.

Problems in the psychology of hard physical work, which we have been studying during the last 12 years, include the study of subjective aspects of force, exertion and fatigue, problems concerning muscular performance and physical working capacity, work motivation, various clinical problems, psychophysiological relations and "explanations" of the psychophysical functions, work curves, etc., various problems concerning physical fitness, training and the general importance of being physically fit. A recent review of our studies in this field is found in two handbook chapters by Borg (6, 7).

The three effort continua

In a perceptual continuum we should try to identify different intensity levels and see how they are related to each other and to corresponding levels in the other two main effort continua: the performance and the physiological continuum. In psychophysical studies interest has been focused on minimum and maximal thresholds, on differential thresholds and on the appearance of the functions between these limits. But in ordinary life there are other intensity levels of interest, such as adaptation and preference levels, stress zones, etc. (see Fig. 1). When we try to adapt to a work situation the load must not be so high that we, in relation to our present maximal working capacity, come too near the stress zone.

A method to determine the perception of physical stress

Psychophysical studies of subjective force and perceived exertion for work on a bicycle ergometer, have shown that the perceived intensity

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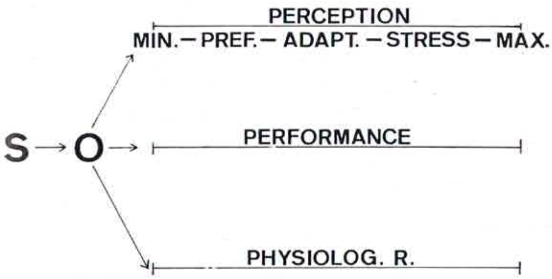


Fig. 1. The figure describes the three main effort continua in physical work. The intensity of the measured stress response varies from a relative minimum to a relative maximum. In all three continua several important intensity levels can be identified, such as preference levels, adaptation levels and various levels of hard stress, and the interrelations between these levels determined.

grows with the physical work load (in kpm/min) according to a positively accelerating function. Mathematically, the increase may be described by a power function with an exponent of 1.6, Borg & Dahlström (8), Borg (3). So in a situation where the work load is increased step by step to higher and higher values, the nonlinearity between the perceived load and the physical load should be kept in mind. If we want the subject to perceive the increase to be the same during the work period the load should increase by smaller and smaller steps.

For clinical use a simple rating method has been developed. The first scale consists of 21 points, where all the odd scale values from 3–19 are anchored with the aid of verbal expressions, such as "very light" and "rather laborious", Borg (1). This rating scale has been used in many studies of normal persons and groups of patients (10, 11). Very high correlations have been obtained between the ratings from the work test and the heart frequencies, e.g. in one study $r=0.85$, Borg (2). The latter scale used consists of 15 grades

Table I. *The scale giving RPE-values, i.e. ratings of perceived exertion*

6		14	
7	Very, very light	15	Hard
8		16	
9	Very light	17	Very hard
10		18	
11	Fairly light	19	Very, very hard
12		20	
13	Somewhat hard		

from 6–20, giving "RPE-values", i.e. ratings of perceived exertion according to Table I.

Before the work the subject is instructed to rate the degree of exertion as accurately and naïvely as possible. The scale, which is presented in quarto format, is shown to the subject and the test procedure (or other kind of work) is explained to the subject. The subject has to answer verbally by saying a number or to point with his finger at the suitable scale value. For example, in a physical work test the subject is shown the scale during the last half minute of each work load and asked to say a number according to how hard the work feels. The values of the RPE-scale grow fairly linear with the work load and the correlation with the ratings and the heart rate is also very high (r about 0.80). As a rough approximation the heart rate for middle-aged people should, for work loads of medium intensity levels, be fairly close to 10 times the RPE-values.

Change of exertion with age

The physical working capacity declines with age but not the heart rate at a given work load. The RPE-values, however, contrary to the heart rates, increase with age for the same work load. This might at first seem a bit incongruent but is explained by the fact that the maximal heart rate decreases with age. In this case the RPE-value therefore gives a better estimation of the change of the physical stress with age than the heart rates. Relative heart rates, e.g. heart rates in percentage of the range, show a similar variation with age as the RPE-values. This relation has recently been illustrated by Borg & Linderholm (10, 11). The authors proposed a correction formula to be used for the reference level in heart rate. A reference level in heart rate of 170 beats per minute for 20-year-old subjects corresponds to about 80 % of the heart rate range in this age group. To get the same relative reference level in heart rate, independent of age, the following formula was proposed:

$$P_{80}=170-{}^{2}/_{3}\,(A\text{-}20),$$

where P is the reference level in heart rate corresponding to 80 % of the range, where 170 beats/min for the 20-year-old subjects is the general reference level and where A is the age in question. The constant ${}^{2}/_{3}$ (or about 0.6) is a rough empirical value and difficult to estimate more accurately owing to difficulties of determining the maximal heart rates in older age groups. If the maximal heart rate decreases by about $^3/_4$ beats per year from 195 beats per min for the 20-year-olds the following simple equation is obtained for the decrease of the maximal heart rate with age:

$$P_{max} = 195–0.75\ (A\text{-}20).$$

In the equations it is presupposed that the basic heart rate is about 70 beats/min and independent of changes with age. For a lower intensity level, e.g. 150 beats/min for the 20-year-olds, corresponding to 64% of the range, the equation becomes:

$$P_{64} = 150–0.5\ (A\text{-}20),$$

that is to say 150 beats/min for a 20-year-old person means about the same degree of physical stress as 135 beats/min for a 50-year-old person.

The studies of the relation between heart rates and RPE-values show that these reference levels of heart rate correspond very closely to the perceived exertion of the individuals.

When testing subjects with a submaximal work test it is sometimes difficult to determine when to interrupt the test. This is true, for instance, in an age-heterogeneous group, where 150 beats/min might be very hard work for some subjects but fairly light work for others. If ratings of perceived exertion are collected during the test, more information is obtained to evaluate when the test should be interrupted.

Heart rate in relation to perceived exertion in some groups of patients

In a study by Borg & Linderholm (11) the relation between heart rates and RPE-values were calculated for patients with coronary heart disease, patients with arterial hypertension, and patients with the vasoregulatory asthenia syndrome. These three groups of patients were then compared with healthy control groups of the same age as the patients. The result of the study showed that patients with vasoregulatory asthenia rated the exertion to be less in relation to the heart rate than the control group. This was especially true for low intensity levels. The same result, although less distinct, was also found for patients with arterial hypertension. The group of patients with coronary heart disease rated, however, the exertion to be higher in relation to heart frequency, particularly at high rating levels. In comparison with the healthy controls, there was a smaller increase in heart rate in relation to a given increase in rating of perceived exertion for all the patient groups studied. The difference found between various patient groups, especially that between patients with coronary heart disease and those with the vasoregulatory asthenia syndrome, is thus of differential diagnostic value.

The physical working capacity in a mixed group of psychiatric clients and a group of mentally retarded

One group of 19 mentally retarded male clients in the age range 16–23 years, one mixed group of 15 young male psychiatric clients, aged 16–25, and one group of older male psychiatric clients, aged 25–36, at the Research and Training Center in Vocational Rehabilitation in Johnstown, Pennsylvania, were studied by means of a physical work test on a bicycle ergometer with stepwise increase of the work load after 4 min work at each work load. The pulse rate was checked towards the end of each work load and the clients also had to rate the degree of perceived exertion according to the RPE-scale. The results were compared with two American reference groups of ordinary young healthy male students at the University of Pittsburgh (12), and another reference group of 26 men aged 17–24 years, who according to several anamnestical, morphological and test criteria were grouped in four groups: lean and sedentary, lean and active, heavy and sedentary, and heavy and active (13).

A measurement of physical working capacity in the form of the work load in kpm/min at a heart rate of 150 beats/min, PWC_{150}, was calculated. In the group of young mentally retarded the mean value of PWC_{150} was 536 kpm/min, for the group of young psychiatric clients 653 kpm/min and for the older psychiatric clients 508 kpm/min. In comparison with the reference groups the total group of young clients had about 15% lower physical working capacity than the group of Pittsburgh students and about 40% lower than the lean–active and heavy–active State College group. In relation to the group of heavy–sedentary young men the clients had about 30% lower working capacity and in comparison with the lean–sedentary group about the same capacity. The clients also rated the exertion to be higher for the same work loads than the normal reference groups. The physical working capacity of these groups of clients must be regarded as very low. We do not exactly know what this result depends upon but it seems probable that it is mainly an effect of the institutionalization and the bad training programs used.

A flexible work test with a feedback system guiding the test course

Most tests of physical working capacity are constructed in such a way that the test conditions are physically equal for all subjects. A rigid time-work protocol is followed. For example, the subjects must work on a series of work loads for the same time at each load. Since working capacity is not equal for all subjects, some subjects are stressed very hard much sooner than others and that the total work time varies a good deal between individuals. To obtain subjective equality of the test situation and also about the same total test time for each subject, it was proposed (4) that the work loads should be chosen in a relative way according to the capacity of the individual. This means that initial work loads are chosen from physiological and anamnestical data, etc., and that the increase of the load during the test depends upon the stress responses of the individual. This idea has recently been tested on a group of young men and a special steering system has been worked out in detail in the form of a feedback system from the reactions of the subjects to guide the test course (9). If the subjects are to work to a maximal value and not to a certain reference level in heart rate, it is necessary to use not only the heart rates as feedback variables, but also ratings of perceived exertion. From these two stress-responses, which complement each other very well, the test course can be steered to give about the same equal test time for each individual.

A model for the quantitative evaluation of the effect of training

Some years ago a model was proposed for inter-individual comparisons of perception (1). This model has been worked out to include other kinds of psychological and physiological responses and other kinds of interprocess comparisons (5). A general stimulus response function may be written: $R = a + k(S-b)^n$, where R is the intensity of the response, a and b are basic intensity levels showing the starting point of the function, S the stimulus intensity, k a measure constant and n the exponent (1, 2). If we want to make inter-individual or other kinds of interprocess comparisons, we must be able to give individual values to the measure constant k. This demands the acceptance of a theory permitting us to propose an equation to solve the measure constant k. According to our reasoning the fundamental statement is put forward to use the range as a frame of reference for interprocess comparisons. The terminal physical intensity levels are set subjectively equal as shown in Fig. 2. Thus, in a physical work test, the maximal strength thresholds for two subjects, S_{t1} and S_{t2} are set subjectively equal, $R_{t1} = R_{t2}$. The measure constant k is then solved in this way:

$$k = \frac{R_t - a}{(S_t - b)^n},$$

Borg (1). Two individual curves may then be drawn in the same diagram showing the differences between the subjects on a series of sub-maximal intensity levels. Thus, for a certain sub-maximal level, S_x, the first subject should react with a much higher response, R_{x1}, than the other subject, R_{x2}. The physical intensity for the first subject that corresponds to the same subjective intensity for the second subject (corresponding to S_x) is thus S_u. Relative response values may then be calculated in the following way:

$$RR_x = \left(\frac{S_x - b}{S_t - b}\right)^n,$$

and also relative stimulus values according to the following formula:

$$RS_x = \left(\frac{R_x - a}{R_t - a}\right)^{1/n}.$$

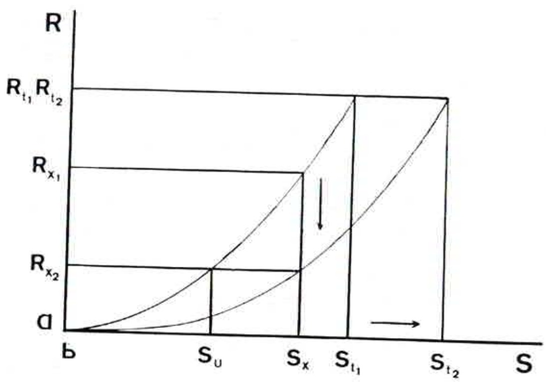
Fig. 2 may thus represent a situation for a person before and after training. When a person has gone through a training program and increased his maximal performance capacity from S_{t1} to S_{t2} the degree of stress response for the sub-maximal level S_x should be decreased from R_{x1} to R_{x2}.

This method of calculating relative response and relative stimulus values may also be of value, when physiological raw values might be misleading as indicators of the intensity of a disease or a slight insufficiency.

Some practical aspects with regard to training

In physical therapy and exercise prescriptions it is sometimes hard to prescribe the intensity of the exercise that is most suitable for a certain patient. One good indicator of the intensity of the exercise is, of course, the heart rate. But some people have difficulty in counting the heart rate or, if they can, they start to become "pulse-counters" who can't do anything without counting pulse rates, and thus focus the interest too much on this activity, and become somewhat too much mentally preoccupied with this. A complement to pulse-counting is to rely on the subjective feeling of effort and fatigue. We should not underestimate people's ability to regulate the work intensity in relation to how hard the work feels. Normally that is what we do when exercising. When the exercise is felt to be too hard, we slow down until we have recovered enough to increase the intensity again, etc.

If we want to supplement exercise prescriptions in the form of statements concerning physical conditions, such as distance, time, speed, etc., and physiological responses in the form of pulse rates,



$$R = a + k(S - b)^n \qquad k = \frac{R_t - a}{(S_t - b)^n}$$

$$RR_x = \left(\frac{S_x - b}{S_t - b}\right)^n \qquad RS_x = \left(\frac{R_x - a}{R_t - a}\right)^{\frac{1}{n}}$$

Fig. 2. The figure shows two stimulus-(performance) (*S*)-response(*R*)-curves for two subjects—or one subject on two different occasions, e.g. before and after training—and a way to calculate relative response and relative stimulus values (see text).

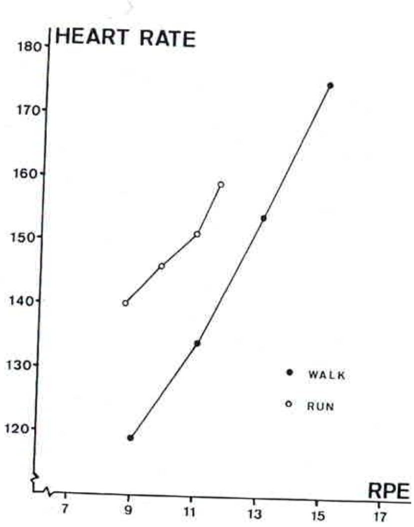


Fig. 3. The relation between heart rate and RPE (Ratings of Perceived Exertion) for walking and running on a treadmill at four different speeds.

with subjective estimates of the perceived exertion, we should train patients to rely on the perception of the exertion that is just right for him. In this connection it is important to know that different kinds of physical activities might cause different degrees of subjective exertion in relation to heart frequency. If it is important to avoid high heart frequencies, lack of knowledge concerning these things might be somewhat treacherous.

In a recent study, subjects about 20 years old had to make performances on a treadmill and alternately run and walk for 5 min. For the four different speeds used, 4–4.5–5–5.5 miles/hour and the rating values corresponding to these speeds the heart rates were between 15 and 20 beats/min higher in running than in walking Noble & Borg (to be published). Fig. 3 gives the result of this experiment. There is thus a great difference between walking and running and it seems possible to exert oneself fairly hard in walking without any risk of the heart frequency reaching such high levels as in running.

A simple fitness test

In a training period after a disease it is important to check the effect of the training. This cannot be done, however, too often in a laboratory, so there is a need for a very simple test that everyone can use. From the point of view of

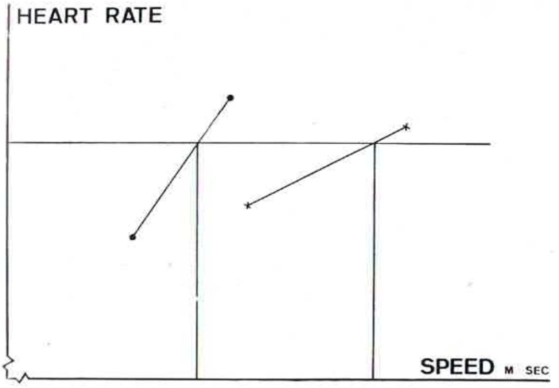


Fig. 4. The figure shows the main principles of a new walk (or run) test, where two dependent variables are used to obtain a measurement of fitness (see text).

motivation it is also important to be able to check one's working capacity fairly often and follow the changes due to training.

There are now some ergometers for home use that are not very expensive to buy. These ergometers, however, are not often designed for accurate control of the changes in work load. Such arrangements are rather expensive and better-quality bicycle ergometers can hardly become everybody's property. Thus, we need a very simple fitness test, using a minimum of technical equipment, which does not require any special technical-motor skill to perform, nor is so exhausting that it has to be carried out under medical supervision. To avoid these equipment difficulties the work load variation might be arranged in conjunction with some daily activities such as walking, running, cycling, etc. One problem here is to check on physical power. When walking on a treadmill, speed and incline are under control, but it is more difficult or relatively expensive to set up equipment for continuous speed during ordinary walks.

A simple fitness test can then be associated with an ordinary day-to-day activity such as walking, in which the technique required to execute the movements is habitual. The difficulty in controlling the speed at which one moves is especially great in maximum exertion. Therefore this is avoided so that the circulatory organs are not burdened "unnecessarily" and instead, the individual is allowed to walk at a moderate pace or jog slowly a certain distance, e.g. 1 km. The course should be relatively flat and suitable for a normal stroll. It is important here that subjects walk at a constant speed. This is scarcely any problem as long as they keep to a normal "walking distance". The time required to cover the distance is taken immediately after arrival and the pulse rate checked. After a short, constant rest period, the performance is repeated, this time with slightly greater effort, though not as much as maximum effort. In this manner, two time-pulse-rates are obtained which differ from one another to a certain extent. In the calculation of fitness, a measurement is then obtained from the pulse-rate-time diagram in the form of the time (or speed) for a certain reference level in pulse-rate. This value can then be compared with previous or subsequent values or with the values of other individuals.

In this test the dependent-independent variable system is changed in an unusual way in comparison with the ordinary tests. The speed is thus not used as an independent variable but is, instead, permitted to vary over subjects depending upon the subjective speed determined by the instruction and the experience etc. of the individual.

Studies have been performed during the spring of 1970 with this test and further studies are in progress. Preliminary results show the utility of the test and since the validity is to some degree self-evident, we would suggest the use of the test as a simple "home test" to follow the progress of fitness and thus motivate to further training.

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