25

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PHYSICAL PERFORMANCE AND PERCEIVED EXERTION

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CONTENTS

I. GENERAL INTRODUCTION ON PROBLEMS AND METHODS

INTRODUCTION

This investigation deals mainly with problems of *physical performance and performance capacity* in relation to different measures of the subjective *perception of exertion*. It is partly a general psychophysical study, but differential problems will also be dealt with in order to suggest a method which makes possible direct interindividual comparisons of perceptions and can serve as a basis for constructing methods for determining physical working capacity starting from psychological variables.

The investigations took their origin from a physical work test on the bicycle ergometer. In several of our experiments the perception of exertion during the said test has been studied. The fact that a test formed the starting-point – the test being often used as an instrument of selection and evaluation of the performance capacity in the field – has to some extent directed the study towards the problem of criteria, *e.g.* the physical performance and subjective exertion of lumber workers.

A symposium report by Spector, Brožek & Peterson (1961) of performance capacity deals with a number of questions of performance capacity and work achievements, mainly from points of view of clinical physiology. Various performance capacity tests such as walking or running up steps or on a treadmill, bicycle ergometer tests etc., are discussed and a great many investigations into their validity are reported. The authors conclude that intense work is necessary before highly reliable methods with good criterion validity can be found. Another recently published work by Gundappa Radjasekharan (1961) summarizes many pertinent problems, e.g. questions of perception (such as problems of fatigue and work), neuromuscular and clinical physiological problems, various test problems, etc.

Physical performance capacity in heavy work is to a great extent limited by anatomical and physiological factors and though several clinical physiologic methods have been worked out, quantitative measurements of this

capacity constitute some of the more controversial problems. The bicycle ergometer test appears to be one of the best both in normal and pathological cases. Recent investigations of these problems have been performed e.g. by Wahlund, H. (1948), Åstrand, P.-O. (1952), Holmgren, A. (1956), Åstrand, I. (1960), Christensen (1960), Linderholm (1960), and Sjöstrand (1960).

The perception of physical exertion and fatigue is an important factor and should be considered in connection with adaptation to work and to general subjective status both in pathological and normal cases. Temporary or chronic physical incapacity produces a physical as well as a mental strain on the individual. It is not primarily the aim of physical training to enable the individual to make maximal achievements, but to provide him with so much reserve strength that he can overcome daily physical strain without a subjective feeling of fatigue and an incapacitating state of anxiety about his condition.

A reduced physical performance capacity is, in fact, one of the most important symptoms causing people to seek medical aid. The data provided by a patient during a clinical examination of performance capacity is often subjectively biased *e.g.* in insurance cases. A patient may experience a reduction of his performance capacity by about two thirds (2/3), whereas the laboratory test only reveals one half (1/2). This may be compared with the perception of reduced speed when driving a car. Judged on the basis of general experience and a pilot-study by Borg (1961), many people perceive a decrease which is more than a half when halving the physical speed. As an initial approximation the reduction of speed when car-driving may be described according to the following power function ($R = cS^2$). The perception of the reduced performance capacity may perhaps be as incapacitating as the test-recorded capacity itself.

In psychophysical investigations one often attempts to study the whole range of variation from a very low to a very high intensity. This leads to the problem af assessing so-called terminal thresholds, or maximal levels. When it comes to physical achievement these levels are relatively easy to assess as compared with many other sense modalities.

In recent years psychophysical methods – for assessing the intensity of different sense perceptions – have been worked out, so that ratio scaling experiments may be performed and the intensity of the perception assessed in ratio units. S. S. Stevens and G. Ekman, especially, have been occupied with methods for such perception measurements and applied them in the investigation of a number of sense modalities. The psychophysical functions thus obtained may be described mathematically with the aid of a power function of the following general appearance: $R=c\ (S+a)^n$ (EKMAN, 1959), where R is the intensity of the perception, c a constant related to the units of measurement, S the intensity of the stimulus and a a constant related to the absolute threshold.

This thesis is partly based on earlier studies and partly on new investigations reported in this book.

The following papers are included and referred to in the text with roman figures as follows:

I. BORG, G. and H. DAHLSTRÖM, The perception of muscular work. Pub. of the Umeå Res. Libr. 1960. 5. 1–27.

II. BORG, G., Perceived exertion in relation to physical work load and pulse-rate. Kungl. Fysiogr. Sällsk. i Lund Förh. 1961. *11*. 105–115.

III. BORG, G., Interindividual scaling and perception of muscular force. Kungl. Fysiogr. Sällsk. i Lund Förh. 1961. *12*. 117–125.

IV. BORG, G. and H. DAHLSTRÖM, A study of the reliability and validity of a physical work test on the bicycle ergometer. Acta Physiol. Scand. 1962. (In press.)

V. BORG, G. and H. DAHLSTRÖM, A case study of perceived exertion during a work test. Acta Soc. Med. Ups. 1962. (In press.)

VI. BORG, G., A simple rating scale for use in physical work test. Kungl. Fysiogr. Sällsk. i Lund Förh. 1962. (In press.)

PROBLEMS

The chief aim of this investigation is to study different aspects of physical performance and perception of exertion. Our psychophysical investigations start with short-time work on the bicycle ergometer. The general psychological problem is here the question as to how the perception of force (pedal resistance) varies with physical force (or power).

As the general psychophysical relations do not immediately admit of interindividual comparisons, a tentative solution of these problems will be presented.

As to the analysis of short-time work on the bicycle ergometer it is of interest to assess a maximal level; consequently special attention has been paid to these problems, the aim being to work out a new work test.

In a study of psychophysical problems of perceptive levels, it seems to me that a highly important level is an ordinary workaday level or a preferred intensity level. In a short study we will therefore deal with this question also.

In order to study the perception of exertion during a fairly long period of work, general and differential psychological studies have been made by

the present author during an ordinary physical work test on the cycle ergometer. As the test plays an important role in our work, one of the first investigations deals with its reliability and validity. The problem is then not only how the perception of exertion grows with the physical power, but also whether the perception values may form a basis on which an indicator of physical performance capacity can be obtained as a supplement to the physiological values. The various results will later be discussed with respect to their inner relations and their relevance in field predictions.

Attention will also be paid to the relevance of the psychophysical relations in certain medical, psychophysiological and semantic connections.

METHODS

In our investigations a bicycle ergometer with an electric brake system constructed by HOLMGREN & MATTSSON was used (1954). A description of this ergometer is given in a paper by BORG & DAHLSTRÖM (1960).

The ergometer was so constructed as to make it possible both for experimental leader and subject to make continuous variations of the physical power. In the case of the subject, this was done with a throttle handle of the motor cycle type connected to a graded resistor.

The power could be varied over a great range from 100 to about 3.500 kpm/min. This variation of power by the turns of the handle or the dial setting occurred according to a positively accelerating function. The deviation from a straight line, however, was very small *e.g.* within a limited range of hundred kpm/min.

When conducting experiments *e.g.* for the assessment of terminal or maximal strength thresholds, where the whole range is used, it may be important to be able to vary the work load linearly with time. A special apparatus has therefore been used which makes possible continuous variation of the speed with which the dial setting adjuster could be varied.

The apparatus has earlier been used by K. J. ÖBRINK and is described by him in detail (ÖBRINK, 1948). It consists of an electric motor which drives a small wheel, the peripheral part of which is made of rubber and is pressed against a larger wheel. The axes of the two wheels are at a right angle to each other. By manually adjusting the small wheel nearer to or further away from the centre of the big one, the speed of the latter may be increased or reduced and varies in the ratio 1 : 5. For further description of the use of the apparatus, see chapter 2 on the CS-test.

During work on the bicycle ergometer the total time of work or the total work performed is also an important factor and of course increases during the whole test. The pedalling speed may be kept fairly constant, or is allowed to vary within narrow limits by making the subject cycle at a certain speed and to correct himself continuously by watching a speedometer. The leader of the experiment had also to check the speed kept by the subject. The cycle ergometer is so constructed that the power is not influenced by changes in speed within 45–75 r.p.m.

The psychophysical methods that have been used are different ratio methods and a rating scale for making possible interindividual comparisons. A method has also been worked out with continuous increase of the power for determining maximal performance with muscle strength and motivation for short-time effort as the decisive factors for the achievements on the cycle ergometer. The psychophysical ratio methods may be divided into two production methods and two estimation methods, viz. ratio or magnitude, estimation or production. When working with the production methods the subject has to set an intensity corresponding to a given multiple, *e.g.* ½ or 2, of a standard intensity, or he has to adjust stimuli so that they correspond to certain figures, such as 10, 25, and so on.

The estimation methods require the subject to estimate a given relation betwen stimuli, i.e. to estimate in per cent how intensely one stimulus is perceived as compared with another, or to estimate the magnitude of one perception in relation to the standard one, which is called *e.g.* "10".

These methods make it possible to obtain perception values corresponding to the respective stimuli as measured in ratio units. The R–S-relation may then be described by a suitable mathematical function. When the production methods are used the stimuli set by the subject form the basis for obtaining relations between perceptions. If *e.g.* the subject is instructed to halve a series of standard stimuli he will set the half values above or below the physically true half values in a way which is characteristic of every sense modality. The psychophysical function may then be described by a simple mathematical function (Ekman 1958 and 1959). How the R-values are obtained is best shown by a graphical description and explanation according to Ekman. The obtained half values are first plotted in a diagram against the respective standard values or reproduced standard values. A straight line is next fitted to the points. The R-values may then be obtained in the following way. If the highest standard stimuli *e.g.* is called "100" in perceptive units, the set halving value for this level (or the more exact halving value extrapolated from the best fitting halving line in the diagram) obviously corresponds to the perceptive intensity "50". To "25" on the R-continuum then corresponds a half value of the former half value and so on. In this way R-values from *e.g.* "100", "50", over "25", "12.5", and "6.25" are obtained with corresponding stimuli.

When working with the estimation methods, relations between *R*-values are more directly obtained. A central measure is calculated for each *R*-value, which is then expressed with the lowest one as a unit.

Most psychophysical functions may adequately be described with the aid of a power function (Stevens 1960). That this mathematical function is a valid way of describing the *R–S*-relations is shown by the fact that when the values are plotted in logarithmic coordinates a fairly straight line is obtained. Sometimes the adjustments to a straight line is better if a constant (the "*a*"-value) is added or subtracted to the *S*-value. When plotting the values in logarithmic coordinates an optimal fitting line is adjusted to the values. The exponent of the psychophysical function, which is the variable in which we are primarily interested, then equals the angle coefficient for this straight line.

During most of the tests recordings were made of the pulse rate, breathing frequency and ECG. Physicians, students, nurses, patients or forest workers served as experimental subjects. The ratio experiments required intelligent subjects able to understand mathematical relations.

The statistical treatment of the work is presented in connection with every experiment and its results.

SOME DEFINITIONS

Physiological reactions of interest for measurement during a physical performance test may generally be given explicite definitions, or they may be defined operationally in connection with ordinary processes of measurement *e.g.* ECG.

The subjective perception of effort, exertion and fatigue, which is the main subject of the present study, on the other hand, is very difficult to define in a general way. This perception is of a comparatively complex nature and consists of contributory factors: sensations from the organs of circulation and respiration, from the muscles, the skin, the joints etc. From a subjective point of view one may speak of the perception of force or pedal resistance, effort, fatigue, strain exertion, heat, pressure, pain or anxiety etc. In pathological cases, moreover, special types of perceptions of pain and anxiety, nausea and breathing disorder will *gestalt* the perception. When doing *short-time work on the cycle ergometer*, where the muscular force appears to be decisive for achievement, it may be convenient for healthy persons to speak of *perceived or apparent force*, effort, exertion, or pedal resistance. For work of relatively long duration, where there is more stress on the organs of circulation and where the length of time and amount of work play a major part, it may be more appropriate to speak of perceived exertion, laboriousness, or fatigue, or if the work is extremely stressing, perceived exhaustion.

The various components of perception may naturally influence the degree of effort or exertion in different ways on different experimental subjects, particularly if comparisons are made between healthy persons and those suffering from some form of muscle or circulatory disease.

The introduction of the above-mentioned treatise by G. RADJASEKHARAN (1961) discusses the conception of fatigue, *inter alia* on the basis of Vitele's definition which deals with three kindred phenomena:

1. "An overt manifestation in the form of reduced output of the task, known as work decrement; 2. A physiological state involving changes in organic functions and the production of chemical products of fatigue; 3. A feeling of fatigue or tiredness". (Cit. from G. RADJASEKHARAN 1961). The author points out that these three factors are extremely difficult to define. Judging from physiological or psychological terms it is very difficult to obtain a general interindividual definition. A physical output-definition may be advantageous and can be given in operational terms.

In order to obtain a clear and concise definition of the subjective continuum for work on the bicycle ergometer, the perception is defined operationally in accordance with our methods of measurement and given instructions. The perception of exertion is defined as the perception that makes the subject respond to the stimulus in accordance with the given psychophysical method and the instruction: 1. "how heavy it feels to pedal, how great the pedal resistance is", short-time work, and 2. "how laborious it feels to work", work of long duration.

II. A PSYCHOPHYSICAL STUDY OF SHORT-TIME WORK ON THE BICYCLE ERGOMETER

GENERAL PSYCHOPHYSICAL STUDIES

The first ratio experiments

The first psychophysical experiments concerned short-time work on the bicycle ergometer (I: BORG & DAHLSTRÖM 1960). The aim was to ascertain the possibility of measuring the intensity of perceived force (perceived pedal resistance), and to see if reliable measures and individual differences could be obtained, and if the *R–S*-relation might be described with the aid of a power function.

The psychophysical method used was the ratio setting method with halving. The experimental subjects had to cycle for 30 seconds at the first standard level, and then immediately afterwards to set the half value and work for about 15 seconds. This procedure was repeated until 6 standard levels had been presented according to a 6×6 Latin Square. (For further details v. paper I.) For a group of four subjects the following preliminary psychophysical equation was obtained according to the method described on p. 9.: $R=c\ (S+100)^{1.6}$. The reliability was computed by means of analysis of variance according to HOYT's formula (GUILFORD, 1954) and was found to be comparatively high: $R_{tt}=0.95$.

When performing halving experiments of this kind consideration should be given to the so-called "time order error" *i.e.* the memory error which arises as a result of the order and the period of time between the perceived stimuli, *e.g.* the given standard stimulus and the reproduced one. Two subsequent simple experiments proved that this error must be taken into account in a study of the perception of muscular force.

Two experiments were planned for the purpose of studying the importance of the period of work from 5 to 100 seconds. They were carried out according to the ratio setting method with halving. The results for short-time work showed that the subject sets lower half values when the standard is perceived for 5 seconds than for 30 to 100 seconds. The perceived performance thus appears to depend not only upon the physical power or force, but also on the amount of work carried out. Here the time of performance seems to influence the perception of the performance (pedal resistance) during the first 5 seconds, so that the resistance is perceived to be less in a shorter period of work than in a longer one.

An analysis of variance was made according to McNEMAR (1957, p. 330). This analysis showed that the time factor had an influence significant at the 0.05 level of confidence. To test the significance of interindividual differences a new procedure was proposed. According to McNemar this difference cannot be tested because no suitable interaction variance could be used when forming the *F*-ratio. However, we have ventured to test the individual variance, s_i^2, against the following combination of interaction variances: $s_{ti}^2 + s_{iu}^2 - s_{tiu}^2$, so that a *F*-ratio could be formed in such a way that the numerator only differs by one term involving the effect to be tested. The individual differences could then be considered amply established. A high reliability coefficient was also obtained according to Hoyt's formula (GUILFORD, 1954) with $r_{tt}=.95$.

The main halving experiment

The above-mentioned experiments served as a basis for subsequent ratio experiments. The problem concerns the more detailed construction of a psychophysical scale for subjective force in work periods of short duration (I: BORG & DAHLSTRÖM 1960). The ratio setting method, involving halving of the stimuli, was used. In order to reduce the influence of the time order error the subjects had to reproduce the standard power as well as to halve it in order to make possible the plotting of the ratio setting values against those reproduced (EKMAN and FRANKENHAEUSER 1957). Five (5) standard power-levels, 500, 700, 900, 1,000 and 1,300 kpm/min., were presented to the subjects. The highest level may be estimated to be lower than one half of the maximal strength threshold of the weakest subject and about one third of that of the strongest one.

The results of the experiment were described with a power function of the following appearance: $R=c\ (S+176)^{1.6}$, where S is measured in kpm/min. Significant differences between the subjects were found, and the calculated coefficient of reliability was high, *viz.* 0.96.

The above-mentioned power function was based on arithmetic means for 12 subjects. In a number of recent psychophysical investigations it has been found that the results of ratio experiments often give skewed distributions. It is now customary to start from medians or geometric means. If the medians for the halving values and the reproduced standard values are taken as starting-points, the psychological equation obtained is: $R=c\ (S+150)^{1.5}$. This function is obtained from the best fitting line in a

TABLE 1

Half-values, $S_{1/2}$, for the standard power level 800 kpm/min. The values consist of means of medians for 5 set values in an ascending and 5 in a descending series.
Number of subjects, O's=22.

O	$S_{1/2}$	O	$S_{1/2}$	O	$S_{1/2}$
1	491.5	9	376	17	538
2	436	10	547	18	447
3	468.5	11	585.5	19	405.5
4	543	12	273	20	387
5	503	13	403.5	21	519.5
6	424.5	14	478	22	619.5
7	450	15	524.5	M	473.8
8	471	16	431.5	M_d	459

graphical plot of the values. The constant 150 is here determined at the nearest 50. As was expected the exponent was somewhat lower, 1.5, than the one obtained from the means, 1.6.

A check on the halving experiments

For a general re-testing of the aforementioned halving experiments, a simple experiment was performed through the halving of one power level (800 kpm/min.) on a group of 22 male students. Every one of the subjects performed 10 halvings, 5 of which were in an ascending and 5 in a descending series. They were given 20 seconds to perceive the standard power and later, about the same length of time, to perform the halving.

The results are given in Table 1, which includes the medians for each subject and for the whole group with $M_d=459$. As is seen in the Table the majority of halving values lie above the physical half. Only 3 of the 22 subjects have a lower halving value.

In a calculation of the psychophysical equation: $R=c\ (S+a)^n$, attention should be paid to a possibile *a*-value and to the time order error. As we cannot calculate these variables in this experiment, the estimation of the *a*-value and the reproduced S, $(S_{1/1})$ is based on previous experiments. If we start from the ordinary straight line: $S_{1/2}=b+kS_{1/1}$ which corresponds to an empirically found halving line, we know that: $a=\frac{b}{k-1}$ and $n=\frac{\log. 0.5}{\log. k}$ (EKMAN 1958). Judging from earlier experiments it would seem that the *a*-value ought to lie between 100 and 200, and that the reproduced $S_{1/1}$ between 780 and 820 kpm/min. Three cases are calculated for the found halving value $S=459$.

1. If $a=150$ and the reproduced S $=800$ kpm/min., the exponent will be $n=1.56$. This exponent is obtained in the following way. We first determine the angle coefficient, $k=\frac{459-b}{800}$, which gives the intercept, $b=459-800\,k$. By inserting this expression for b and the value for $a=150$ in the equation $a=\frac{b}{k-1}$ we get $150=\frac{459-800\,k}{k-1}$ and $k=0.641$. Thus the exponent is $n=\frac{\log. 0.5}{\log. 0.641}=1.56$.

2. A lowest probable exponent is obtained if a is put at 100 and $S_{1/1}$ at 820, $n_2=1.39$.

3. A highest probable exponent is obtained if a is put equal to 200 and $S_{1/1}=780$, $n_3=1.73$.

This experiment shows that if halving alone is considered, the exponent of the psychophysical function for the given experimental conditions with short-time work on the cycle ergometer lies between 1.4 and 1.7.

Ratio estimation

A psychophysical experiment concerned with the perception of force during short time work on the cycle ergometer was also carried out with the ratio estimation method according to Ekman (1958). We employed the power levels often used for physical work tests so that a direct comparison with psychophysical scaling for long-time work in such a test could be made. The chosen levels were 300, 600, 900, and 1.200 kpm/min.

The experimental subjects were 12 male students aged between 20 and 30 years. During a period of 20 seconds they had to perceive a certain level, and immediately afterwards another one during a 20-second period, after which they rested for 30 seconds. The levels were presented in pairs at random, 12 pairs only, 6 in an ascending and 6 in a descending series within the pairs. Half of the experimental subjects performed the experiment in a reversed order. The subjects had to estimate in per cent how intensely the weakest stimulus in the pair was perceived as compared with the strongest one.

Immediately after this experiment another one was performed in which all the power levels were presented in sequence, as is often the case in work tests, and the experimental subjects had then to estimate the last perception of pedal resistance in relation to all the previous ones.

The result is seen in Figure I. where two curves represent the first and the second experiments plotted in logarithmic coordinates. The psychophysical equation corresponding to the result of the first experiment (1)

in Fig. I. is $R=c\ (S+200)^{1.8}$. The corresponding equation for comparisons with levels in an ascending series, as in physical work tests (2), was of the same appearance although the a-value was approximately $a=300$. If, in the latter case, the a-value is disregarded, the exponent $n=1.2$ is obtained. Adaptation to a straight line in logarithmic coordinates, however, will then be poor. It will thus be seen that there is a fair dependence of

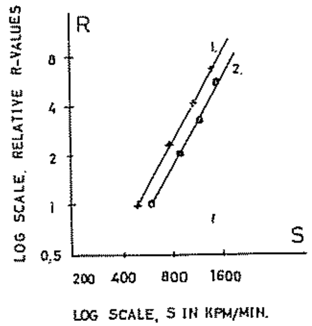

Fig. 1. Results of two experiments, 1. and 2., with the method of ratio estimation. The relative perception values are plotted against the corresponding stimulus values, S, in logarithmic coordinates.

the magnitude of the exponent upon this a-value. The experiment gave us reason to suppose that two different functions could be obtained if the comparisons were made in ascending or descending series within pairs so that a lower a-value is obtained in a descending order.

Ratio production: A variety of doubling experiments

In previous psychophysical experiments on short-time work a series of halving experiments was carried out. As pointed out by Stevens (1957) due regard should be paid to the factor of hysteresis in psychophysical experiments. In this connection somewhat different functions are obtained if comparisons are made of stimuli in the ascending or in the descending series. If, with a mathematical function, one describes a general relation between perceived and physical stimulus, due consideration should be given to this and to the method employed. This has been the case in a number of psychophysical investigations allowing the experimental subject *e.g.* to perform both the "halving" and the "doubling" of standard stimuli.

In this investigation we have attempted to see if an exponent of the same magnitude can be obtained when "doubling" as when "halving".

As a psychophysical method the ratio setting method was used, although in a somewhat modified form. The exponent of the "doubling experiment" is supposedly of about the same magnitude as that of the "halving" and we therefore started from the earlier obtained function with the exponent $=1.5$. Instead of carrying out the experiment in the usual way with "doubling" of the standard stimulus we reversed the procedure and changed the instructions for the experimental subject, so that in accordance with the above function a predictive ratio between the power levels should be obtained.

In this case we have attempted to predict a "doubling" of the physical power. With the standard stimulus $S_1=700$ and the adjusted power $S_2=2S_1$, S_2 becomes $=1{,}400$ kpm/min. In this way the ratio between the corresponding R-values is obtained by insertion of S in the equation:

$$R=c\ (S+150)^{1.5}, \text{ and } \frac{R_2}{R_1}=\frac{1{,}550^{1.5}}{850^{1.5}}=2.5.$$

The experimental subject was instructed to adjust a level perceived to be 2.5 times as great as the initial resistance S_1. A distribution for individuals of S_2-values about 1,400 kpm/min. was thus predicted.

Twenty-four male physicians or medical students in Umeå, aged between 20 and 40 years, placed themselves at our disposal as experimental subjects. All of them were in a good physical condition with a maximal strength threshold exceeding 3.000 kpm/min. for short-time work on the cycle ergometer.

The experimental subjects had first to perceive the standard power level for 20 seconds and then, for about the same period, to perform the ratio setting, *i.e.* increase the work load until the pedal-resistance felt to be 2.5 times greater. This was repeated in ascending, descending, descending and ascending series so that four assessments were obtained for each person. In the ascending series the experimental subjects had to adjust the resistance from the initial level; in the descending series from a level set by the experimental leader immediately after the standard level and about 3.5 times as high.

The result are given in Table 2 showing means of the 4 power values in kpm/min. As is seen the range is great, from 1,100 to 2,200 kpm/min., with the median $P_{50}=1{,}411$ kpm/min. The values are somewhat positively skewed with $P_{25}=1{,}347$ and $P_{75}=1{,}543$ kpm/min. The mean is $1{,}478 \pm 48$ kpm/min.

The uncertainty in the exponent may simply be said to correspond to the variation from P_{25} to P_{75}=three times the standard error, which implies a confidence level with $P<0.01$. Starting from the mean we obtain the interval 1,344—1,612 kpm/min. at the same confidence level.

The exponent of the power function may be assessed according to

TABLE 2

Results of the experiment with ratio setting. The values consist of means of 2 values in ascending and 2 in descending series obtained by increasing the power from the standard level 700 kpm/min. with 2.5 times in subjective units, $S_{2.5}$.

Number of subjects, O's=24.

O	$S_{2.5}$	O	$S_{2.5}$	O	$S_{2.5}$
1	1107	10	1384	19	1561
2	1254	11	1393	20	1645
3	1267	12	1406	21	1667
4	1337	13	1415	22	1792
5	1340	14	1430	23	1859
6	1343	15	1431	24	2239
7	1351	16	1489	M	1478
8	1354	17	1505	M_d	1411
9	1376	18	1525		

Ekman's (1958) method from the straight ratio setting line, as pointed out earlier. The mean gives the exponent $n=1.42$ and the extreme limits of the confidence interval $n=1.62$ and $n=1.26$ respectively if we start from the a-value 150. The median gives the exponent $n=1.53$ and the extreme limits 1.33 and 1.62.

The method we employed to retest the size of a psychophysical exponent seems to be a quick and adaptable one. A prediction may be made for a stimulus level chosen arbitrarily, or for some special reason, from a power function obtained earlier. The deviations of the results from the predictive level may be tested together with the significance in the ordinary way and the uncertainty of the exponent can be estimated.

Naturally, in the first place a simple factor between the R-value should be chosen. As a check on the generality of the function a certain variation in the choice of factor is useful. As our investigations show, such a difficult ratio setting multiple as 2.5 may be used. (The single high value of 2,239 kpm/min. may have been due to misguided ambition at the time of the experiment. The experimental subject spontaneously stated later that he had probably set a very much too high resistance.)

This experiment thus supports the previously obtained results and an exponent about 1.5.

Discussion

The investigations of the perception of muscular force for short-time work on the bicycle ergometer have shown a positively accelerating function with an exponent of about 1.6. Our uncertainty range from 1.4 to 1.8 cannot from an intermodal viewpoint be regarded as great in comparison with the variation in the exponent for different sense modalities. STEVENS (1960) gives the following ranges, – "The power function has been observed by many experimenters (*e.g.* EKMAN 1959). It has been shown to hold on more than two dozen continua, and the exponent, "n" has been found to range from about 0.33 for the brightness of a target perceived with dark-adapted eyes to about 3.5 for the subject intensity of electric current (60 cps) passed through the fingers".

An a-value of 150 to 200 units has also been found in the psychophysical power function: $R = c\ (S \pm a)^n$ for the perception of muscular force or effort during short-time work on the bicycle ergometer. The value may be interpreted in such a way that when cycling without any physical pedal resistance the subject still perceives some effort, relatively speaking.

Further support for the validity of the given exponent is found – independently of our investigations – in a recent investigation into the "apparent force of handgrip" by STEVENS & MACH (1959). Their psychophysical study gave an exponent of $n = 1.7$.

Naturally, further experiments may be performed for the assessment of the psychophysical function for short-time work. Quite a number of general psychophysical methodological problems still remain to be solved, however, for instance the time order error and the significance of the range, differences between the method of psychophysical estimation and production and, last but not least, the question of the justification of starting from the experimental subject's statements concerning numerical ratios in order to obtain subjective ratio scales.

An ingenious method presented by STEVENS (1960) seems to be of great interest in this connection. The method implies that cross-modality assessments are made. It also seems possible to apply the method to the continua in our investigations, and it may also be an answer to the question of validity raised above.

INTERINDIVIDUAL SCALING AND PERCEPTION OF MUSCULAR FORCE

Introduction

In a paper by the present author (III: BORG, 1961) the problem of interindividual scaling was discussed, and a proposed solution was tested by a simple experiment. The problem has not often been observed, but is of fundamental theoretical and practical importance. The old philosophical

question whether "Hylas perceives the red colour in the same way as Philonous does" may serve to illustrate the problem.

Psychophysical ratio experiments do not make possible immediate interindividual comparisons of the intensity of perception. The ratio scale yields relations between perceptions, but not levels revealing anything about the intensity in relation to some general intersubjective point of reference. In most practical situations a simple rating method is, therefore, superior to a ratio method.

This rather fascinating problem of absolute interindividual comparisons may, perhaps, be solved psychophysiologically in the future. Our aim here is not to base our reasoning on any such presumptions, but to attempt from psychological assumptions to find a possible solution which will be empirically illustrated by an example from the perception of muscular force.

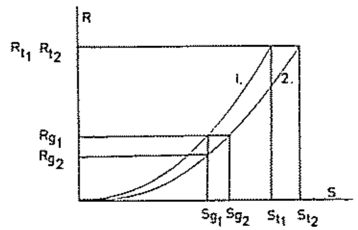

Fig. 2. Two hypothetical curves for the perception (R) of Weight (S) for two subjects, 1. and 2. The latter is considered the stronger and is able to lift more than the first, $S_{t_2} > S_{t_1}$ corresponding to $R_{t_2} = R_{t_1}$. The perception of a submaximal stimulus, S_g, may be read direct from the curves and *interindividual* comparisons may be made.

Our proposed solution is based *inter alia* on the assumption that the intensity of the individual's perception is evaluated in relation to his present and previous experiences, *i.e.* to the whole range of intensities as a frame of reference. Our assumption cannot be verified empirically, but from the viewpoint of common sense it may be considered more or less probable. To begin with we maintain that there is an interindividual variation of the stimulus range, and that for every individual's stimulus range there is a corresponding perceptive range. We assume that the intensity of an individual's perception is unambiguously determined by its place in the perceptive range. Our main assertion is that the perceptive range and the intensity of the perception at the terminal threshold are equal for all normal individuals.

The exponent or constants of the psychophysical equation may also be of interest from the point of view of differential psychology. But no direct comparisons of the intensity of perceptions can be made.

In Fig. 2 two hypothetical curves are given for the perception of weight for 2 subjects = 1 and 2. The latter is considered to be stronger and is able to lift more than the first $S_{t_2} > S_{t_1}$. The terminal threshold is here defined as the heaviest weight a subject can lift. Two curves may be drawn in the same diagram if $R_{t_1} = R_{t_2}$. The perception of a submaximal stimulus may be read directly from the curves for both subjects and interindividual comparisons may thus be made.

As the terminal threshold and the stimulus range can be empirically determined for each individual it is possible to make interindividual comparisons. In the equation $R = c\ (S + a)^n$ the unit of measurement c is determined for every individual if R_t is given a suitable numerical value:

$$c = \frac{R_t}{(S_t + a)^n}$$

Experiment 1

The psychophysics of muscular work is a sphere which appears to be particularly suitable for the application of interindividual scaling according to the above-mentioned principles. The degree of subjective force or effort ought in normal cases, to have a strong correlation with the measured physical performance.

An experiment was carried out for the interindividual scaling of perceived muscular force during work on the bicycle ergometer. (III: Borg, 1961.) By the ratio setting method ratio scales were obtained for 4 individuals. Determinations of the terminal threshold were also made in accordance with the method of adjustment.

The constant c in the power function $R = c\ (S + a)^n$ (Ekman 1959) was assessed by putting $R = 1{,}000$ for $S = S_t$.

As the unit of the perception of force was chosen 1/1,000 of the subjective force perceived when the terminal threshold is attained. This unit is called "*vig*" and 1 "*vig*" is thus $= R_t/1{,}000$.

Experiment 2

Like most theoretical models, our method for interindividual scaling cannot be verified or falsified in an absolute sense. But its applicability and use may be valued and its degree of probability empirically proved.

If our reasoning is valid the correlation ought to be strongly negative between R-values for a submaximal level S_i, and the terminal thresholds S_t. In Fig. 3 we have tried to visualize this and also the fact that the distribution of R-values is positively skewed if the terminal thresholds in physical ratio units are normally distributed in the population.

This method for validation presupposes that some other relevant indicator of the level of intensity of the perception may be obtained. A

subjective rating scale has proved to be useful in other connections. (See Chapter 3.) We have therefore used this rating scale in this experiment.

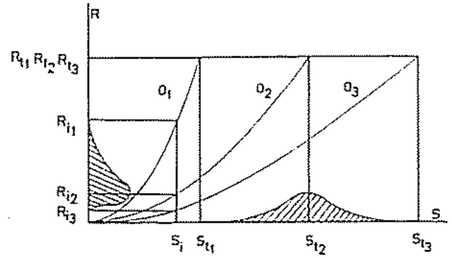

Fig. 3. Distribution of terminal thresholds, S_t corresponding to one and the same subjective R_t-value, and distribution of R_i-values for a submaximal stimulus value, S_i.

In accordance with the above reasoning we arranged an experiment where 20 subjects, 14 men and 6 women about 20–25 years of age, had to rate a submaximal level during work on the bicycle ergometer according to a 21-graded rating scale. Three terminal thresholds and three ratings per individual were determined for the level 2,000 kpm/min.

TABLE 3

Results of an experiment on the validation of the method for interindividual comparisons. The S-values consist of cycling strength thresholds on the bicycle ergometer measured in kpm/min. The R-values consist of ratings from a 21-graded rating scale and have been given by all individuals. O's for one and the same submaximal power level.

O	S	R	O	S	R
1	3137	15,5	11	3176	18,0
2	2991	17,5	12	2815	18,5
3	2704	15,5	13	3283	15,0
4	2550	18,5	14	3431	12,5
5	2763	18,5	15	3577	13,0
6	2167	18,0	16	3339	16,0
7	3470	16,5	17	3073	16,5
8	2396	18,0	18	2626	18,0
9	1877	20,5	19	1372	21,0
10	3541	14,5	20	1352	21,0

The results are given in Table 3. A rank correlation according to Spearman was calculated and found to be very high, $rho = -0.83$.

Discussion

In this chapter we have ventured to propose a method for making direct interindividual comparisons of the intensities of perceptions. The problem is a very old one and considered to be insoluble. In an absiute sense this may be true, but for making interindividual comparisons serving as reliable and valid guides the method seems to be very promising. The method may also be suitable for other perceptive continua. There is, however, one drawback bound up with the determination of the S_t-level. For example, perceptions of pain, or the degree of motivation, may in certain cases have an undesirable effect. For the perception of muscular force this does not seem to be of great importance but for some other continua the disadvantage may be greater. For normal individuals the individual differences in muscular performance are very high and probably much greater than the differences in most other sense modalities.

This method for interindividual comparisons may also be applicable in studies of changes in individuals. Such changes may depend on either an increase in the performance capacity after physical training, or a decrease in connection with some disease. In normal cases physical training or motion is not intended to increase the maximal physical performance capacity in itself, but the sensation of stress and strain in normal work should be reduced. When the terminal threshold has been increased the perception of one and the same submaximal level should decrease, or one and the same perception level, *e.g.* a preference level, should correspond to a higher physical performance level. When there is a decrease in the working capacity the condition is the reverse.

In pathological cases such as depressive states of inhibition, asthenic states of invalidity, hysterics or euphoric conditions it is possible that there are cases of perception changes without corresponding change of performance, or the reverse may happen with performance changes. The high rank correlation between ratings for a submaximal level and corresponding maximal thresholds showing the validity of the theoretical model for interindividual comparisons, may also be considered good validation and a theoretical anchoring of the subjective rating scale. This is very important as it lends further support to the use of the rating method and its superiority as compared to ratio scaling methods when direct comparisons of intensity levels of perceptions are made.

A WORK TEST FOR SHORT-TIME WORK ON THE BICYCLE ERGOMETER. "THE CYCLING STRENGTH TEST" "CST"

Introduction

In psychophysical investigations of physical work, problems concerning the assessment of the upper performance or maximal strength threshold are apt to arise.

In the introduction to this thesis mention is made of the criterion-directed nature of the investigations. Forestry forms a type of field work of great importance in Sweden, and people occupied with it are engaged in heavy and strenuous physical activity. Methods applicable in assessing the forest worker's mental and physical performance capacity will therefore be of great practical importance.

In studies of the individual's physical performance it is of interest to obtain information on his subjective perception of exertion in connection with physical achievement. As a supplement to different physiological reactions to physical strain such subjective values should be used as an indicator of the performance capacity, *e.g.* in selective and predictive connections.

A method has been worked out by the present author for assessing maximal strength thresholds in short-time work on the cycle ergometer. This method is based on the experience of heavy physical work and a general working analysis of forest workers, the performance of athletes and their modern training methods, physiological and psychological considerations and certain preliminary experiments.

An analysis of the achievements of forestry workers will demonstrate the importance of several factors concerning performance differences, *e.g.* muscularity, endurance, technical skill, general talents, motivation, and the ability to plan work, etc. Some of the most important factors referred to above may be evaluated quantitatively. With tests on the cycle ergometer in the case of normal healthy persons, work on the cycle ergometer may be so arranged that muscularity, adaptation to circulation and motivation of physical work will be the decisive factors. Motivation here may be of two somewhat different types, *viz.* motivation for short-time force effort and motivation for more long-range performance.

In many physical work tests, use is made of a physiological measure as an indicator of performance capacity, *e.g.* pulse reaction in physical exertion. Sometimes no such physiological indicator is employed, and the work test is more in the nature of a psychological behaviour test. A drawback with some of these tests may be seen in that only small groups of muscles have often been engaged in the performance. It is of great interest to construct a test of muscular force where large muscle groups are involved and where some form of criterion-connected motivation for physical performance plays a decisive part.

In such a test attention must be paid to several factors. Many stimulus factors, particularly the size or the speed of the power level increase, the length of working time and pauses and suitable pedalling speed are of interest. In addition, special consideration should be given to the above-mentioned adaptability of circulation and to the motivation. The psychophysical methods far assessing the upper strength threshold may also be varied in different ways.

Preliminary experiments performed by the present auother indicate that the normal variation range of maximal thresholds extends from approximately 1,000 to 4,000 kpm/min. Many cycle ergometers have an upper limit below 4,000 kpm/min., *e.g.* the one used by us and mentioned in Chapter 1, notably a limit at about 3,500 kpm/min. Since the average maximal level in a normal group seems to lie below 3,000 kpm/min. with a standard deviation of some hundred kpm/min., however, the cycle's capacity need not be that high in the majority of normal cases.

As earlier stated, a pedalling speed of 50 or 60 r.p.m is generally used in physical work tests. In our experiment we have adapted 60 r.p.m., and the ergometer is so constructed that the power is not influenced by slight changes in the pedalling spead.

To avoid the possibility that the adaptation of circulation influences the assessment of muscular force, the length of the working period should be less than 1 minute. As regards the "physiologic background" of bodily work, Sjöstrand (1960, page 201) states: "When the exercise is of very short duration, it can be carried out anaerobically and the oxygen requirements met afterwards by balancing of the so-called oxygen debt. Accordingly, the muscular power that can be developed will determine the working capacity.

In the case of more prolonged work, *i.e.* with a duration of one minute or more, the magnitude of work performed becomes dependent on the quantity of oxygen that can be distributed to the working muscles in addition to the power that the muscles can develop".

On the other hand, the working period should not be so short that only rough or unreliable measurements can be obtained. With a working period of 30 seconds, for example, and a linear power variation from 0 to more than 3,000 kpm/min., the power increase will be more than 100 units per second. In relation to the dispersion and the difficulty in assessing the upper limit to the exact second it is preferable that the working period should not be very much below one minute unless unreliable measurements are obtained.

The motivation of force effort is a factor difficult to eliminate. In the majority of investigations of muscular force, motivation is included as an important part-factor. This may be a disadvantage if an indicator of the muscular capacity is desired in a limited sense. But it may also be an

advantage if some measure of criterion in field work is desired, and where the motivation may also be assumed to have a similar influence during tests as during work in the field.

Psychophysical methods generally used for threshold assessments are the method of limits, the method of reproduction, and the constant methods (Guilford 1954). As, *inter alia*, only a few assessments of muscular strength for work on the cycle ergometer may be performed in quick succession, without any important involvement of the cardio-vascular system, it appears more expedient to employ the method of reproduction or the method of limits with the power variation in ascending sequence.

The test based on these principles and empirically proved is named "The Cycling Strength Test", "C S T".

Apparatus

The previously mentioned cycle ergometer was employed in the assessment of muscular strength. The apparatus mentioned in the introduction was attached to the ergometer to adjust the speed and the continual variation of the power. As the power increase on the ergometer follows a somewhat positively accelerating curve in relation to the dial setting scale, the increasing tendency was counteracted by the speed with which the adjustable wheel was driven. This was changed in accordance with a negatively accelerating curve so that an approximate linear relation between the power increase and the time could be obtained. The speed was adjusted manually by the speed-adjustment wheel adapted to a special centimeter-scale speedometer. By checking the time of the experimental leader's manual adjustment chronometrically it was found that the error amounted to only a small percentage. The precision of the method is also seen in the high reliability coefficients obtained (cf. below).

Material

In connection with a more extensive investigation of physical and mental performance capacity during the summer of 1961, a group of permanently employed forest workers (Mo and Domsjö Ltd.) were subjected to a physical work test. Participation was voluntary, but as full pay and subsistence allowance were granted by the Company, there was a good response.

The subjects' age in years was $M=45.2 \pm 1.2$, height $M=172.9 \pm 0.8$, body weight $M=72.0 \pm 1.1$ and working capacity according to PWC_{170}, $M=1.195 \pm 23$. In Table 4 the means, dispersions and ranges have been arranged together with the relative values of wage per working day during

TABLE 4

Means, standard deviations, S.D., and ranges, for some variables which describe the sample of 57 subjects. Relative values of wages are also included for all lumber workers (N=137) in those districts from which the material was taken.

Variabel	Mean	S.D.	Range
Age	45.2	8.5	27—62
Height	172.9	5.8	161—183
Weight	72.0	7.9	56—91
PWC_{170}	1,195	170	875—1,525
Wage, $N=57$	1.07a	0.19a	0.57a—1.38a
Wage, $N=137$	a	0.21a	0.46a—1.39a

the precedly year (1960). In order to give an impression of the representativeness of the sample of 57 lumber workers (cutters), wages have also been included for the total group of 137 permanently (with more than 200 working days per year) employed forest workers in those districts from which the material was derived. For reasons of secrecy the values in crowns per day have been transferred so that the values have been accounted for in relation to the mean of the larger group as an unit. The mean of the sample is slightly above that of the total group.

From 3 to 4 hours before the experiment every subject was subjected to a physical test. An ECG was also taken to check any possible pathological heart reaction. A few definitely pathological cases with severe ECG changes during exercise were not included in the experiment. Some subjects with pain in back or knees and some subjects with ECG abnormalities were, however, included.

Method

For assessing the maximal thresholds a modified method of limits was chosen with a power variation in an ascending series up to the point where the experimental subject could no longer pedal or maintain the stipulated speed of 60 r.p.m. but fell below 45 r.p.m., the latter one being the lowest one used with regard to the power, see Introduction.

A start was made from a low initial-level performance, *viz.* circa 500 kpm/min. The variation range was set at approximately 3,000 kpm/min. (from 536 to the ergometer's upper limit 3,577 kpm/min.). The power increase was kept constant with the time, the choice being 50 units per second so that a total working time of circa 45 seconds could be obtained.

When the first assessment was completed, which took 42 seconds on an average, a new initial level was chosen for each individual. In doing this the previous final level was chosen as a starting-point for the calculation

of a power level corresponding to a working period of 45 seconds below the obtained final level. If the initial level was thus below 536 kpm/min. the experimental subject had to cycle at this initial level for a period of such a length that the total time could be estimated at 45 seconds or somewhat below. The maximal assessments were then repeated a number of times (See Chapter 3). At this juncture we are not interested in a closer study of the work curve obtained, but only in the first assessments indicating the maximal force or strength level. Three assessments proved to give reliable measures. After a working period of 45 seconds the experimental subject had to rest for 15 seconds after which a new assessment was made so that one assessment per minute could be obtained.

Results

The results of the "cycling strength test", "C S T", are given in Fig. 4. The values in the Figure represent the means of the three successive assessments. The mean for the group is $M=2{,}450$ kpm/min. and the standard deviation is S.D.$=550$ units.

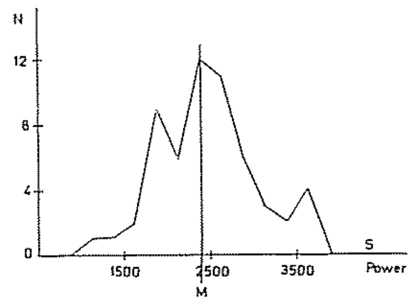

Fig. 4. Result of the cycling strength test, CST, showing the distribution of means of the first three maximal thresholds in power, kpm/min. Number of subjects, $N=57$.

In the test the reliability was estimated in that the results of the first assessment were correlated with the second, after which the correlation coefficient $r=.94$ was obtained. The means of the first and the fourth assessments have been correlated with the means of the second and third. The correlation coefficient thus obtained was $r=.96$.

In Table 5, some correlations have been arranged in the estimation of the validity and specificity of the test. The correlation matrix shows correlations between the cycling strength test, CST, and the working capacity according to the power at the pulse 170, PWC_{170}, and to the rating "very laborious", PWC_R, for work on the bicycle ergometer. Correlations with wages for 1960, 1961 and the mean of 1960–1961 are also included. The

TABLE 5

Correlation coefficients between the cycling strength test, CST, and the working capacity according to the power at pulse 170, PWC_{170}, and to the rating (R) "very laborious", PWC_R. Correlations with wages for 1960, 1961 and the mean of 1960—1961 are also included. The CST (1) denotes that only one determination (the first) is taken while the CST values are founded on three (3) assessments.

Variables	1	2	3	4	5
1. CST (1)					
2. CST	.96				
3. PWC_{170}	.26	.24			
4. PWC_R	.51	.49	.22		
5. Wage 60	.50	.56	.19	.43	
6. Wage 61	.51	.52	.22	.52	.57
7. M. wage 60—61	.57	.60	.23	.54	

At $r=.26$ is $P \leq .05$ and at $r=.33$ is $P \leq .01$.

CST (1) denotes that only one (1) determination (the first) is taken while the CST values are founded on three (3) assessments. The tests of working capacity PWC_{170} and PWC_R are discussed in more detail in Chapter III.

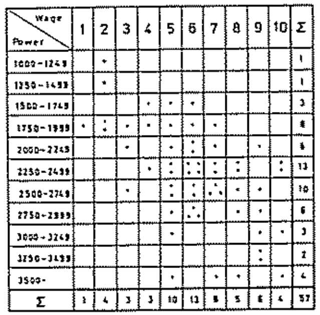

Fig. 5. Scatter diagram showing the correlation between wage (in 10 classes) and results of the cycling strength test, CST, (in power unit, kpm/min.).

As seen from the correlation matrix, the validity of the test expressed as the correlation with wages is high, $r=.60$. The correlation is also seen by the scatter diagram in Fig. 5. The correlation with the physical (*P*) working (*W*) capacity (C) assessed from the rated degree of exertion (*R*) during work on the cycle ergometer, PWC_R is $r=.49$. The correlation with the working capacity estimated on the pulse reaction, PWC_{170}, is $r=.24$. See further Chapter III.

Discussion

The result of the investigation has proved to be very promising. The cycling strength test, CST, has revealed good reliability and validity. The group examined, however, is relatively small and consists of a special group of employed forest workers. Thus the correlation coefficients should not be taken too literally as representatives of another group. The material was not homogeneous as regards age and has therefore probably increased the range and by that the size of the correlations. On the other hand, it may be assumed that the group was more homogeneous with respect to performance and motivation than many other groups. The latter should in turn have resulted in a reduction of the correlation.

We know of no other investigation of a similar type that has revealed such a high validity. An explanation of the good correlations may be that for physical field performance the most important variables such as leg muscularity, motivation, and possibly to some extent also the adaptation of circulation, may be assessed with the CS-test in a very reliable manner. The motivation for physical performance, which is a decisive part of the test performance, is presumably of a type similar to that included in field work.

The criterion which has consisted of the income per working day is not a particularly reliable measurement of the performance capacity. This appears from the low correlation coefficient between the two different annual wages, $r=.57$. If the validity correlation is corrected for attenuation in the criterion, with a reliability coefficient of $r=.80$, the corresponding validity correlation is $r=.67$.

As the performance of the test only takes a few minutes it is very timesaving. The period of work and the length of pauses between the assessements may of course be slightly altered in future experiments. In this case we have chosen short pauses in order to stress the organs of circulation. See further chapter III.

In this connection it has been of interest to discriminate in a normal group. In investigations concerning *e.g.* patients with reduced working capacity or weak motivation, the test should also prove useful. For a definite evaluation of the validity of the test further investigations and cross validations should be carried out on different and larger groups of experimental subjects.

THE PREFERENCE LEVEL

Introduction

The term "preference level" was mentioned in the previous section on interindividual scaling. By this I mean a level that is perceived by the individual as being just about right or comfortable. It may also coincide with an optimal achievement level or adaptation level (cf. HELSON, 1951).

In psychophysical experiments on levels, attention has mostly been paid to absolute thresholds or some type of terminal thresholds. In this connection it would appear that the so-called preference level has been regrettably neglected. The possibility of assessing this level appears to be good for a number of sense modalities, *e.g.* perferred reading light, car-driving speed, or "comfortable listening level", SOMMERVILLE (cit. STEVENS, 1955).

In order to make possible interindividual comparisons as regards the preference level, a suitable general reference point must be obtained. When a patient's subjective perception of exertion for physical work is estimated in clinical practice, he is often asked how strenuous it feels to walk up steps or the like. The possibility here of obtaining an entirely general point of reference is limited. There is yet another possibility, namely that when interindividual comparisons within a homogeneous occupational group with fairly well-defined physical tasks are made, the performance asked for in the experiment may conveniently refer to some specified occupational physical achievement.

Experiment

In connection with investigations of the working capacity of lumber workers, mentioned in an earlier chapter, the latter had to perform preference level adjustment during work on the bicycle ergometer. The subjects were instructed to adjust a work-load – for about half a minute – which approximately corresponded to a preferred level in heavy forest work *e.g.* when de-branching. The experiment was repeated ten (10) times with about a half minute pause between each assessment.

The results revealed a great interindividual range from 200 to 1,500 kpm/min., the mean for the whole group being $M=701$, and the dispersion S.D.$=98$ kpm/min. The distribution of the 57 experimental subjects' means was positively skewed with the median, $M_d=649$ kpm/min.

The reliability of the assessments was calculated by correlating the means for the first and fourth assessments with those of the second and third, and further by correlating the means of all the odd assessments with

those of the even ones. Thus the first correlation was $r=.93$, and the second $r=.988$. As is seen the reliability is very good.

The results have also been correlated with other measurements of performance. The correlation with the working capacity according to subjective rating, PWC_R, was thus $r=.15$, and the correlation with the working capacity PWC_{170} $r=.00$. A significant correlation was obtained with the maximal performance for short-time work on the cycle ergometer, CST, with $r=.42$. The preference level was also seen to correlate with the mean wage for 1960–1961 with $r=.35$.

Discussion

The aim of this study has been to show that the preference level may be a reliable measurement of practical significance. The correlations are only to be looked upon as rough indicators of connexions as the distribution of the preference values was skewed. Furthermore, according to the leader of the experiment, some of the subjects might not quite have understood the instruction.

With regard to the level it may be of interest here to compare the results with the work test PWC_{170}. In this case the adjusted preference level corresponds on an average to about half of the working capacity according to PWC_{170}.

It may be of interest to apply the assessments of preference levels to a number of other modalities. In normal as well as in pathological cases the preference level and its changes in relation to the maximal level, the absolute threshold, or forced adaptation level that does not coincide with the preference level, may prove to yield information on more general characteristics of personality.

III. A CLINICAL AND PSYCHOPHYSICAL STUDY OF LONG-TIME WORK ON THE BICYCLE ERGOMETER

A GENERAL INTRODUCTION CONCERNING THE RELIABILITY AND VALIDITY OF A WORK TEST

Introduction

In the assessment of physical working capacity, it is necessary to pay attention to the individual's ability to perform heavy work during a long period, whereby the organs of circulation are subject to great stress. The work load that the individual can manage at a so-called "steady state" level, *i.e.* with retained physiological balance in relation to the demands, is often taken as an indicator of the working capacity.

A method often used in the estimation of physical working capacity (SJÖSTRAND 1947, 1960) is to let the subject work on a cycle ergometer for 6 minutes on each of a series of work loads increased step by step until the pulse rate reaches a level of at least 150 beats/min. With this method the physical working capacity may be indicated at the power level where the pulse rate is 170 beats/min. after inter- or extrapolation ($=PWC_{170}$). Another method to indicate the physical working capacity from submaximal levels is that of P. O. ÅSTRAND (1952) and I. ÅSTRAND (1960), which transforms the pulse frequency for one or several power levels to a value of estimated maximal o_2-consumption with the aid of a special nomogram.

Experiment

Our psychophysical investigations of the perception of exertion are closely related to work tests. We have, therefore, made a study of the reliability and validity of the above-mentioned work test. (IV: BORG and DAHLSTRÖM, 1962.)

The material of our study consisted of 42 twenty-year-old forest workers which formed a fairly representative sample (DAHLSTRÖM & HAMBRAEUS, 1958). The cycle ergometer test was first performed in the summer of 1957 and was then repeated in the spring of 1958. The test was carried out with successively increased power levels, and for a period of 6 minutes for each level: 600, 900, 1,200 kpm/min. and so on. The pulse frequency was assessed after working periods of 2, 4, and 6 minutes, and the breath-

ing frequency after 3 and 5 minutes for each level. Results from a twenty-mile skiing race (30 kilometers) were chosen as a criterion of condition for test validation.

The results revealed very good intratest correlations between pulse rates from 4 to 6 minutes – as high as $r=.98$, and re-test correlations as high as $r=.76$. The highest correlation with the skiing race was found with the PWC_{170}-values, $r=.54$. The importance of the increase of time from 4 to 6 minutes for this validity correlation was compared with the importance of the power level increase from 600 to 900 kpm/min. It was then found that the latter gave the greatest contribution to the validity.

The intratest correlations for breathing frequency were as high as $r=.95$, and re-test correlations were up to $r=.84$. The correlation of the breathing frequency with the pulse rate or criterion, however, was throughout very low. The morphological variables, height, weight and chest width did not show any significant correlations with the criterion, but the latter two variables correlated slightly with the breathing frequency.

Discussion

This study of the work test on the cycle ergometer has shown that the reliability and the validity of the test are good.

The reliability assessments of the test that have hitherto been made have been concerned with retests. By correlating physiological measures obtained during the course of the test and of fundamental importance for the evaluation of the result, intratest correlations may, however, be obtained showing reliability correlations in a more restricted sense of the word: individual inconstancy dependent on some days' lapse of time has not been allowed to influence the coefficients.

Most validity coefficients that are reported in the literature are lower throughout (c. f. SPECTOR, BROŽEK & PETERSON, 1961). The relatively high correlation that we have found may be explained by the fact that the group tested was fairly homogeneous in respect of age and pulse-rate reaction, which makes pulse 170 an interindividually significant referecnce-point, though it is heterogeneous with regard to the tested physical working capacity. The criterion used in the form of results of a skiing competition also seems to be a form of physical activity to a great extent loaded with the same intervening variables of fitness as the ergometer test. The validity questions will be dealt with further in the following section on differential studies.

GENERAL PSYCHOPHYSICAL STUDIES

Introduction

When investigating the psychophysics of muscular work on the cycle ergometer longer periods of work than those described in part. II should also be the object of study. As the organs of circulation may be subjected to severe stress it is possible to obtain further information about an individual, which is of general as well as of clinical importance. The perception of exertion during a long period of cycling should also be influenced by the reactions of the heart and respiratory organs, which play a greater part in the sum total of the perception than in short-time work.

Many difficulties are bound up with a general psychophysical study of how the perception of exertion varies with the physical power during longer periods of work on the ergometer. As the variable comparison power has to be perceived a comparatively long time after the standard power, memory errors may play an important part. It is hardly possible to use any form of the method of ratio or magnitude production here. Owing to factors of *e.g.* fatigue, only a relatively small number of power levels become objects of study, and it is therefore difficult to adapt a psychophysical function to the results obtained.

Experiments 1 and 2

Two scaling experiments with the methods of ratio estimation and magnitude estimation are reported in a paper by the present author (II: Borg, 1961). The following power levels were chosen: 100, 300, 600, 900 and 1,200 kpm/min. This choice was made in accordance with the work test, and also for the purpose of obtaining a great variation in range. The last level, 1,200 kpm/min., is about the mean of the working capacity in a normal group of young men to judge from PWC_{170}, according to results obtained *e.g.* by Borg & Dahlström, IV (1962).

As in the ordinary work test on the bicycle ergometer, every power level was experienced for a period of 6 minutes. The perception of exertion was only defined generally and vaguely for the subject as "how laborious it feels".

A fairly homogeneous group of 12 male medical students served as experimental subjects.

In the first experiment with the method of magnitude estimation, the perceptions of the power levels were related to the memory of one and the same level, *viz.* 300 kpm/min. The power levels were presented to the subjects in pairs with 300 kpm/min. as the first one in the pair.

In the experiment with the method of ratio estimation the power levels were presented to the subjects in an ascending series. The subject had to estimate the memory of the previous levels in relation to the perception of the current one. He had also to rate the degree of exertion according to a 21-degree rating scale.

During the experiments an ECG was taken and the pulse rate was checked for the 4- and 6-minute periods.

The results of the two ratio scaling experiments were fairly congruous. In order to form an idea of the reliability of the perception values an analysis of variance was made of the values obtained in the first experiment. A reliability coefficient was obtained according to Hoyt's formula (Guilford 1954) with $r_{tt} = .91$.

As an initial approximation the results were described as a psychophysical function with the exponent $n = 1.1 - 1.2$. The rating values varied slowly and negatively with the power and with the ratio values.

Experiment 3

A ratio scaling experiment was also carried out (VI: Borg, 1962) in connection with a study of subjective rating and pulse reaction during work on the cycle ergometer, whereby the rating scale presented below (p. 39) was used. The same ratio estimation method as described previously was used. The levels were presented to the experimental subjects for 6-minute periods immediately succeeding each other in an ascending sequence, as in an ordinary physical work test. The result was in good agreement with those already obtained. If the a-value was disregarded in the equation: $R = c\ (S + a)^n$, the exponent $n = 1.2 - 1.3$ was obtained. Adaptation to a straight line in logarithmic coordinates was, however, poor. With an a-value of 200 kpm/min. the exponent is $n = 1.6$, and with an a-value of 300 kpm/min. $n = 1.8$.

Discussion

The ratio scaling experiments on subjective exertion during a physical work test with levels in an ascending sequence showed good agreement. The perception of subjective exertion thus follows a positively accelerating curve in relation to the increase of power level.

When interpreting the first experiment (II: Borg 1961) we did not calculate with any a-value in the equation: $R = c\ (S + a)^n$ as an initial approximation. With four levels to adapt a function the latter will be relatively uncertain. The R-value obtained for $S = 100$ pointed towards a relatively small a-value below 100 units. If an a-value of circa 100 units is included in the above-mentioned equation with the exponent $n=1.1-1.2$, an exponent $n=1.3-1.4$ is obtained. If the R-value for $S=100$ is disregarded, a relatively high a-value of 200 to 300 units and the exponent $n=1.5-1.7$ is obtained.

In a recently published work by EKMAN (1961) a number of general psychophysical methodological questions are raised in connection with an experiment on the intensity of taste perception. Different psychophysical functions are thus obtained according to choice of stimulus-range, psychophysical method, and standard stimulus. Ekman here suggests a power function of the following general appearance:

$$R=\alpha+cS^n$$

It would appear that the results of our investigations could also be described with the aid of the latter power function. In the first experiment the exponent n is approximately $=1.5$ and α about $=1/3$ of the R-value for the lowest level, 300 taken as the unit. In the third experiment the exponent n is approximately $=1.6$ with α about $1/2$ of the R-value for the lowest level, 300 kpm/min.

Ekman's investigation shows that the choice of standard stimulus as a point of reference is of decisive importance for the appearance of the function. This fact is also of interest for the interpretation of our results. The R-value obtained for $S=100$, for example, was made with the latter presented after the standard level, 300 kpm/min., while other comparisons were made with the levels in an ascending sequence.

If a psychophysical function is desired, describing in a general way the variation of subjective exertion in relation to physical power during work on the cycle ergometer, many experiments should naturally be planned with a rotation of the experimental conditions and the levels in ascending and descending series, etc. A comparison of such a general function and the more special physiological function obtained in a physical work test with the levels in an ascending succession, however, is not directly possible. The results of our investigations make possible a direct comparison of the physical work test mentioned above.

Many general psychophysical methodological problems remain to be solved before different functions of the sense modalities can be assessed exactly. As there are good possibilities of planning physiological measures in physical work tests, it is our intention to return to these problems in a more extensive biophysical connection.

DIFFERENTIAL PSYCHOPHYSICAL STUDIES

Introduction

Differential psychophysical studies may be of interest for the estimation of physical working capacity and even contribute to the understanding of psychophysiological relations and more general individual traits.

The ratio methods previously used give relations between perceptions, but not levels for immediate interindividual comparisons. A question of great importance, therefore, is how to "anchor" the subjective values according to the ratio scale so as to make such comparisons possible. This question will be touched upon here and further discussed in connection with problems concerning a quantitative semantics in chapter V.

During physical work both the pulse reaction and the subjective rating of exertion may be considered measures of physical performance. They should correlate with each other, but the subjective rating, being an expression of the individual's total physical and mental reaction to exertion during work, might be expected to provide additional information over and beyond that of the pulse reaction alone. Together with certain other physiological and psychological measures, measures of subjective exertion should also be able to provide increased information for the estimation of a patient's working economy and motivation in physical work, *e.g.* in cases of insurance and pension claims.

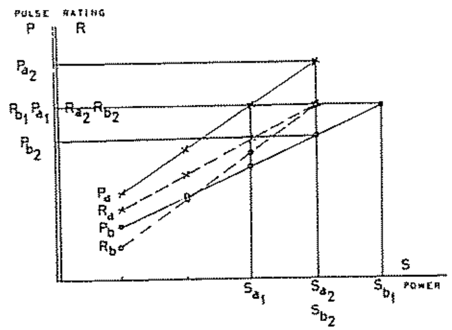

Fig. 6. A hypothetical model for assessing physical working capacity in power, kpm/min., from pulse rates (P) and from subjective ratings (R) for two subjects A and B. The interindividual reference point for pulse values (*e.g.* 170 beats/min.) is P_{a1}, and P_{b1} corresponding to two different power levels, S_{a1}, and S_{b1}. The reference point for ratings is R_{a2}, and R_{b2}, which in this special case corresponds to one and the same power level S_{a2}, and S_{b2}.

One possibility to anchor the subjective values seems to be to combine the ratio scaling with some form of determination of the levels according to a rating scale. The physical working capacity during work on the bicycle ergometer can thus be determined both from the pulse rates and from the complex and "motivation-loaded" perception of exertion.

Fig. 6 gives a graphical description of how the working capacity might be determined on the basis of the subject's pulse values (P), or perceived values (R) expressed in physical power (S) for work on the bicycle ergometer. The working capacity for two subjects A and B are shown in the figure according to the pulse rates with continuous lines and according to the rating with broken lines. These hypothetical cases show how two different values of the physical working capacity, S_{a1} and S_{b1}, according to the pulse rates, might give one and the same indicator of working capacity according to the ratings, S_{a2} and S_{b2}. These two measures of the physical working capacity should correlate with each other, although the correlation figures might not be higher than allowing these two measures to complete each other as indicators of physical working capacity.

In a pilot-study of perceived exertion and physical working capacity by Borg & Dahlström (1962) these ideas or hypotheses have been tested empirically. A slight correlation was thus found both between the physical working capacity determined from pulse rates, and from subjective ratings between these variables and an independent criterion in the form of *e.g.* a skiing race. The validity of the two measurements of working capacity was about the same.

A simple rating scale for use in physical work tests

In a paper by Borg, VI, (1962) an account is given of a study on the method for determining physical working capacity from subjective ratings. The subjective rating scale applied in the above-mentioned pilot-study by Borg & Dahlström (1962) has been closely studied in a more extensive investigation of physical working capacity. The scale consists of 21 grades where all the odd scale values from 3 to 19 have been anchored with the aid of verbal expressions. The latter were so chosen that the scale should receive a good interindividual validity, *i.e.* only well-defined terms with a comparatively good intersubjective, constant meaning were chosen. The scale was presented to the subjects in quarto format with equal distances between the figures and in the following terms:

3 Extremely light, 5 Very light, 7 Light, 9 Rather light, 11 Neither light nor laborious, 13 Rather laborious, 15 Laborious, 17 Very laborious, 19 Extremely laborious.

The individuals were subjected to the physical work test mentioned in the Introduction with a gradually increasing load from 300 kpm/min., and with a 300 kpm/min. increase between each level. The working time for each level was 6 minutes. During the work test an ECG was taken to check any possible pathologic signs and to record the pulse frequency. The subject had to give the rating during the last minute of each level.

A fairly normal sample of 73 subjects took part in the test. Their ages ranged from 20 to 30 years in two-thirds of them, the rest from 30 to 40 years. The results showed that the ratings grow according to a curve somewhat negatively accelerating with the physical power. The physical working capacity was calculated both according to the power level at pulse 170/min., PWC_{170} and to the level at the rating value that corresponded to pulse 170, which was $R=16.5$, PWC_R. The coefficient of the product-moment correlation between the two measures of working capacity was $r=.61$. The correlation between the pulse values and the ratings for each of the submaximal power levels was about $r=.40$, and for the whole work test, including all power levels, the correlation with ratings and pulse rates was $r=.85$. This may be considered a very high validity coefficient and also shows that the reliability of the scale is good. It might, therefore, be very useful as a supplement in estimations of physical performance capacity.

A validation study of the subjective rating scale as an instrument for estimating physical working capacity

As there is great need for instruments in evaluating physical working capacity we have chosen to test the suitability of the rating scale in a predictive connection. Seeing that lumber work constitutes a field in which physical working capacity is an important vector of the field performance, we decided upon an investigation with a group of normal lumber workers. The aim was to ascertain how the physical working capacity, determined by the pulse reaction during work on the cycle ergometer, PWC_{170}, and the working capacity determined by the subjective rating, PWC_R, correlated with an external criterion of the performance capacity in the form of wages.

In the above-mentioned investigation on the use of the rating scale we started from the rating 16.5 in order to determine the level. In the present case we started from the rating 17 as a more simple point of reference corresponding to the 21-graded rating scale's expression "Very laborious"

The investigation was carried out simultaneously with the one reported on page 26. The correlation matrix presented there also showed correlations with the working capacity according to PWC_{170} and PWC_R together with other variables, *e.g.* wages, as a criterion. The different test measures here showed a number of correlations of great interest. Thus there was a correlation of working capacity according to PWC_R with physical strength according to CST circa $r=.50$ and with working capacity according to PWC_{170}, $r=.24$. The correlation between PWC_R and the average wage per day 1960–1961 was as high as $r = .54$, while PWC_{170} values only correlated $r = .24$ with the corresponding field criterion of the working performance.

As several of the experimental individuals did not reach a puls exceeding 150 beats per minute during the physical work test, the PWC_{170}-values should be considered less reliable. According to this method extrapolation from lower pulse levels implies a considerable degree of uncertainty. Consequently a group was chosen from the material that attained a pulse exceeding 150 beats per minute. This group consisted of 33 individuals whose PWC_{170}-values gave a correlation with wages of $r = .44$, while the PWC_R-values did not now correlate as high, but gave the correlation $r = .37$. The CS-test still gave a high correlation: $r = .49$. (At $r = .34$ is $P \leq .05$ and at $r = .43$ is $P \leq .01$.)

The investigation has thus shown that a rating scale can be of great help in the assessment of physical working capacity for work on the cycle ergometer. This appears to be the case particularly during work with a group that is not only heterogeneous in respect of the results of the investigated variables, but also heterogeneous in some intervening variable coinciding with the investigated variable itself. If, for example, an investigation with regard to the pulse reaction and its upper "ceiling" is carried out on a heterogenous group, the method appears to be an important supplement to the assessments according to PWC_{170}. If no correction is made *e.g.* for the maximal pulse level, the latter method implies that the reference point, pulse 170, is really of absolute interindividual significance.

As previously shown, correction for attenuation may appreciably increase the correlation when the reliability of the criterion is relatively low. If the criterion reliability is $r < .80$ the PWC_R-values' validity will be higher than $r = .60$ after correction.

A PHYSICAL WORK CURVE FROM INTERMITTENT CYCLING STRENGTH ASSESSMENTS, CS-TESTS

Introduction

We have previously described a method to assess physical performance capacity for short-time work on the bicycle ergometer, *viz.* the CS-test. The nature of the test was such that the performance capacity would be chiefly dependent upon muscularity and motivation. We will now show how this test may be extended to a work curve so that a more general measurement of physical working capacity may be obtained.

Work curves have been studied ever since the days of Mosso and Kraepelin. According to WOODSWORTH & SCHLOSSBERG (1954) these curves have of late fallen into obscurity as, among other difficulties, it is hard to obtain ergograms that are comparable from time to time and from one experimental subject to another. The authors also state that the work curve may be highly dependent upon personality factors.

Serial analysis of the performance of more complicated and conflicting tasks, such as those of the colour-word test, have been performed by SMITH & NYMAN (1959) and have proved to provide important clues to the operational definition of clinical personality syndromes.

Among other workers, SEASHORE (1951) and RADJASEKAHARAN (1961) have given summaries of their own and other investigations into working performance and work curves, etc. A method for assessing physical working capacity with a continuous increase of the work load during a period of 5 to 10 minutes is described by LEHMANN and MICHAELIS (1941) and also used by RONGE (1948). CHRISTENSEN, ÅSTRAND *et al.* (1960) have made investigation on *e.g.* intermittent muscular work. Criterion-directed problems of working performances in the field, working-analysis, workers' analysis, and similar questions have been presented in detail by GHISELL and BROWN (1952). A study by LUNDGREN (1959) deals with "The practical use of physiological research methods in work study"

Many muscularity tests have dealt with relatively limited groups of muscles. It would be of interest to plan a test in which muscle performance including greater muscle groups could be measured. By repeating such a test intermittently with short pauses between the assessments it may be possible to obtain a work curve where the adaptability of the organs of circulation is of great importance for the level and form of the curve, in addition to the influence of motivation and muscularity.

Experiment

An investigation was carried out in which the working capacity from intermittent short-time work on the bicycle ergometer was assessed. For every individual a work curve was obtained consisting of maximal thresholds according to the method described in Chapter II.

The same cycle ergometer, and an apparatus for the variation of speed, giving linear power variation with time were used as in previous experiments. The power was increased by 50 kpm/min. per second, and the subject worked for a period of 45 seconds and then rested for 15 seconds. The choice of working time and pause was based on previous preliminary experiments and on the perception of exertion of the subjects.

The investigation was performed on the same material of 57 lumber workers as described in Chapter II, and was a direct continuation of the experiments described there. An ECG was taken simultaneously with the assessment of the maximal thresholds and the pulse-rate determined from the ECG sheet at these upper levels. Twenty (20) assessments were made for every subject. Two individuals were unable to carry through the whole test, the one retiring after 10 and the other after 13 assessments, each stating that they could endure no more. However, the final values of these two persons have been included with those of the rest. The experimental subject was not allowed to know how many assessments were to be made, but was given to understand that the test would be repeated several times. However, just before the last assessment notice was given that only one more remained.

The results of the investigation are presented in Figure 7 and Table 6. In the Figure there is a work curve describing the means of 20 assessments for the whole group. As will be seen the curves descend rather abruptly at the beginning from 2,600 kpm/min. to a stabilized level of circa 2,150 kpm/min. Already after 10 assessments the curve has reached a fairly stabilized level. A curve corresponding to one standard deviation below the means has also been plotted. Those pulse values which correspond to the maximal values are also seen in the Figure. Already after the first assessment the pulse was relatively high, or 150 beats per minute. After some assessments it increased to a relatively constant level of about 157 to 158 beats per minute. It appears that the dispersion of the maximal thresholds war fairly great. One drawback of our cycle ergometer in this connexion was that the power could not be increased beyond 3,577 kpm/

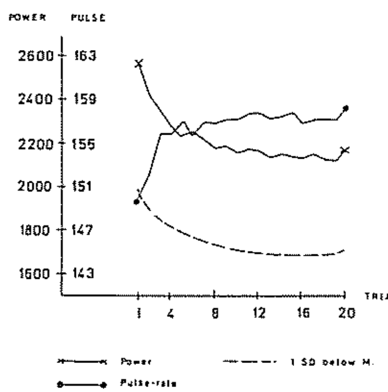

Fig. 7. Work curve consisting of 20 maximal thresholds in power, kpm/min., and corresponding pulse rates. A curve showing values 1 S.D. below the mean is also included. Subjects=57 lumbermen.

TABLE 6

Correlation matrix showing correlations between the results of the two work tests on the bicycle ergometer, and means of wages per day from two years. Work (W) curve, 1. denotes the three initial values per individual (=CST, Chapter II.), M for means of the three middle values (9, 10 and 11), and F for means of the three final values (18, 19 and 20). PWC_{170} is the working capacity according to pulse 170, and PWC_R the working capacity according to the rated exertion "very strenuous"

Variables	1	2	3	4	5	6
1. W. curve 1 (=CST)						
2. „ „ *M*	.83					
3. „ „ *F*	.75	.92				
4. PWC_{170}	.24	.27	.32			
5. PWC_R	.49	.53	.48	.22		
6. *M*, wages 60—61	.60	.61	.62	.23	.54	
7. *M*, w. curve (*I*+*F*) or M_{tot}						.65

At $P<.05$ $r=.26$ and at $P<.01$ $r=.33$.

min. In the first assessments this level was reached by 5 subjects. Two subjects' "initial levels" (se below) was also equal to 3,577 kpm/min. Only one person, however, succeeded in reaching the power ceiling during the 20 assessments.

Table 6 shows correlation between the results of the work curve experiment and those of the work test previously described. The initial level (*I*) from means of the first three determinations *i.e.* the *CST*-values, the middle level (*M*) consisting of means of the three medium values (9, 10 and 11), and the final level (*F*) of means of the three final values (18, 19 and 20) of the work curve, have been correlated with the working capacity according to pulse 170, PWC_{170}, and according to the rated exertion "very strenuous", PWC_R, and with the means of wages per dag in the years 1960 and 1961.

The correlation matrix in Table 6 shows the reliability and validity of the test to be very good. A reliability coefficient has also been calculated on the split-half values so that the means of all the odd assessments are correlated with the even ones. Thus a highest reliability coefficient of $r=.997$ is obtained.

The correlation between the final level and the middle level of the work curve is $r=.92$, which is in conformity with the result that the individuals have reached a fairly stabilized level of the curve. The middle level and the initial level correlate $r=.83$, and the initial level and final level, $r=.75$. The decrease in the correlation seen here may be the result of the influence of other factors than muscularity determining the level of the curve, viz. adaptability to circulation and motivation for long-time work. The increase in the correlation between working capacity according to PWC_{170} and the different levels of the work curve from $r=.24$ to $r=.32$ support the fact that the adaptability to circulation is of increasingly greater importance for the results.

As pointed out in an earlier chapter, the correlation with PWC_{170} should not be taken too literally in this connection as the group was very heterogeneous in pulse reactions. Furthermore, many experimental subjects did not reach a pulse rate of 150 beats per minute.

The different levels of the work curve also show high correlations with the working capacity when based on the subjective rating of exertion, PWC_R. Here the correlations are about $r=.50$.

As an external and independent criterion of the physical working capacity, use was made of the mean income per day during the years 1960–1961. As will be seen, the different levels of the work curve give very high correlations with this criterion or $r=.60$. As the correlation between the initial and final levels is not higher than .75, a high correlation may be anticipated if the test results are based on the means of the initial and final levels or on all the values. This is in fact the case and the very high correlation of $r=.65$ is thus obtained. If this is corrected for attenuation, with the criterion reliability $r_{tt}<.80$, a correlation between the test and the criterion of $r>.70$ is obtained.

Discussion

The method with intermittent assessments of maximal thresholds in short-time work on the cycle ergometer, yielding a work curve, has given interesting results. As this investigation forms part of a research programme concerning the working capacity of lumber workers and planned in collaboration with a psychiatrist and a clinical physiologist and carried out with clinical, psychometric and personality-diagnostic tests, the results will be further examined from the points of view of personality diagnosis and physiology. The method, however, has proved to be very reliable and has good validity. It should therefore be very useful as an instrument for selection and prediction. Naturally, other groups of experimental subjects should be subjected to follow-up investigations and validation. It would also be of interest to test the suitability of the method on different groups of pathological cases, psychasthenics, "insurance neurotics", psychopaths, depressive patients etc.

The periods chosen for intermittent work – cycling for 45 seconds and resting for 15 – should obviously be considered preliminary. A closer

physiological analysis may perhaps show that a different distribution of work and rest periods gives better results.

As is seen from the results, the pulse very soon reaches a relatively high level. If we desire a quickly obtained indicator of the maximal pulse, the method appears to be useful for this purpose as well.

Already when planning this work test we considered the suitability of allowing variables of importance for physical performance in the field (muscularity, adaptation to circulation, and motivation) to play a decisive part. Our intention has not been to determine in detail the extent to which these variables influence the performance. There seem to be excellent possibilities for a more detailed psychological and physiological analysis. The results of the work curve should then be put in relation to other work tests, PWC_{170} and PWC_R and others. In contradistinction to the other tests, working capacity determined by pulse reaction PWC_{170} is not in this way charged with motivation. A person with good motivation and muscularity, but in poor condition with regard to the circulatory adaptation for long-time work, should achieve an abruptly falling work curve. If he were in good physical condition the work curve would, on the other hand, have a flatter form. A relatively flat work curve may also possibly be obtained with a group of aggravating experimental subjects. In this case, however, the level should be considerably lower than that for the well-motivated groups with good adaptation to circulation. For instance, in conscious or unconscious aggravation it appears to be easy for the patient to attain a low level. It should, however, be more difficult for an aggravating subject to achieve a work curve congruous in form to that of a normal person. It seems to be very difficult for the aggravating subject to foresee that an initial force effort, due to stress on the organs of circulation, should give a characteristic form to the regression of the curve.

Apart from the differences between individuals in level and regression, it might also be of interest to study the size of the variance. As shown by Smith & Nyman (1959) the size of the residual variance, in conflict-charged performance, is combined with primitive-hysteroid personality traits. Perhaps a vegetative lability may be revealed in a serial analysis of these normally slightly conflict-charged physical performances and show that they coincide with diagnostically important personality traits. The ordinary course of performance in the colour-word test with a relatively high "secondary" regression and variance in psychopaths (Nyman & Smith, 1959) may also in certain cases coincide with an analogous course in physical work.

IV. SOME PSYCHOPHYSIOLOGICAL RELATIONS

Introduction

Our investigations have concerned the psychophysics of muscular work from the point of view of general psychology and differential psychology. It is of interest to compare the psychophysical relations to the physiological ones. The physiological and psychological reactions caused by the same stimuli are obviously different aspects of the same change in behaviour. Both the subjective perception of the exertion and the physiological reaction to physical work may be considered indicators of physical strain. Theoretically it should be possible to explain the psychophysical function with the aid of different physiological functions.

Only a few psychophysiological investigations of this kind have been carried out. One of the best known of these investigations is that of STEVENS & WOLKMANN (1940) on the subjective pitch and the maximum of sensitivity along the bacillar membrane.

The constants and exponent of the general psychophysical equation should be related to the corresponding variables in certain general physiological equations of importance and relevance for the perception. Even the individual deviations from these general relations are naturally of great interest both in normal and in pathological cases. Every individual's psychophysical equation for a definite, limited perceptive continuum should be studied in connection with certain relevant physiological functions so that an "explanation" of the deviations from the general psychophysical tendency may be obtained. From a clinical viewpoint such an abnormal psychophysical curve gives rise to a suspected physiological disorder.

At this juncture only two of the more important physiological parameters in connection with the psychophysiology of muscular work will be discussed, *viz.* the concentration of lactic acid in the blood and the pulse reaction during work.

Perception of exertion and pulse rate

As the pulse reaction during physical work is a very good indicator of working capacity and the degree of exertion, it is of interest to study

the psychophysical function in relation to the pulse variation during work on the cycle. As shown *e.g.* by CHRISTENSEN (1931, 1955) and by SJÖSTRAND (1960) the number of pulse-beats/min. grows linearly with the power for long-time work on the cycle ergometer during which the pulse reaction shows the individual's aerobic adaptability. This linear relation was also found in our investigations. In an experiment reported by BORG, VI, (1962) on subjective rating and pulse reaction, the following pulse averages were found in a group of 54 individuals, at 300 kpm/min.: 93.8 pulse-beats/min., at 600: 117, at 900: 141.7 and at 1.200 kpm/min.. 165.7 pulse-beats/min. As is seen the pulse increases linearly with the power and may be described with the following general equation: $P=b+c\times S$, where P is the pulse at a certain power level, b the basic pulse level, c a measure constant and S the physical power. In this case the equation is: –

$P=70+8\times 10^{-2}\times S$, where S is measured in kpm/min.

Our psychophysical function for the perception of exertion during a work test increases according to a positively accelerating curve with the exponent $n \sim 1.6$. There is some covariation between the pulse and the perception curves but the positive acceleration of the latter cannot be "explained" with the aid of the pulse reaction.

The above discussion applies to general psychophysiological relations. It is naturally of interest to compare the individual's deviations in perceived exertion from the average tendency with those of the pulse reaction. In the aforementioned investigation of subjective rating and pulse reaction by BORG, VI, (1962) a strong correlation (.83) was found between subjective ratings according to the 21-graded rating scale and the number of pulse beats per minute during a work test. Thus the variation of individual ratings could to a great extent be based on or "explained by" the pulse variations.

Perception of exertion and blood lactate concentration

It is an old belief that the concentration of lactic acid in the blood is a poison of fatigue and that consequently the perception of exertion and fatigue is to a great extent dependent upon concentration of lactic acid in the blood. In normal persons this concentration can vary from 10 to 15 mg/100 ml to 110—130 mg/100 ml (HOLMGREN & STRÖM, 1958). As pointed out by them "the blood lactic acid concentration reflects the degree of anaerobic metabolism in the working muscles, and may thus be used as an index of how adequate the blood flow and oxygen transport to the muscles are in relation to the need". Characteristic deviations from the average changes in the lactic acid in connection with the physical load are obtained in various pathological cases or in well-trained sportsmen.

In the above-mentioned work by HOLMGREN & STRÖM an account is given of the variation of the lactic acid content in relation to the physical power during work on the cycle ergometer. Different groups of experimental subjects were studied, for example a group of 52 young male laboratory assistants, doctors and patients without any ailment of relevance

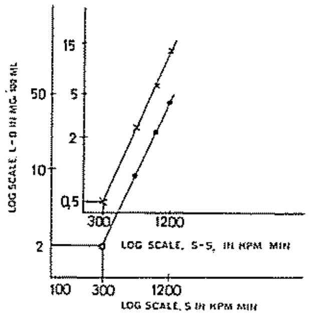

Fig. 8. Variation in lactic acid in relation to work load for two groups of subjects reported by HOLMGREN & STRÖM (1958). The results are here presented in logarithmic coordinates.

in this connection, and also a group of competitive male cyclists. As regards age these groups correspond fairly with ours. The experimentees were subjected to the same work test as previously described and the lactic acid content was determined in blood samples taken during 5 or 6 minutes at every power level by arterialized finger prick or through an indwelling arterial catheter.

In order to compare our psychophysical functions with the function described by the lactic acid concentration in relation to the power, we have made a rough interpretation of HOLMGREN & STRÖM's results in terms of a biophysical equation. In Figure 8 we have given the curves for both groups of experimental subjects presented by the authors in Figure 2. We have plotted the curves in a diagram with logarithmic coordinates so that the biophysical function is clearly seen. The horizontal axis represents the power and the vertical one the lactic acid values.

As is seen in the Figure the points are well adapted to a straight line, which proves that a power function may be obtained. The following ~~biophysical~~ equation describes the function: —

$$L=b+cS^n \text{ or } L=b+c\ (S-S_0)^n$$

where L is the lactic acid concentration at a certain power level, b the basic lactic acid level, c a measure-constant, S the power, S_0 a power value

where the curve begins to accelerate and n the exponent that describes the form of the curve. Further $L=b$ for $S \leq S_0$.

For the "normal group" the following equation is obtained: –

$$L=13+7\times10^{-6}\times S^{2.2}.$$

The group of racing cyclists is on a lower basic level with b about equivalent with 10, with about the same exponent, but with an S_0-value approximately equal to 300 kpm/min.

The positively accelerating psychophysical function that we found both in short- and long-time work on the cycle ergometer, may thus be connected to the variation of the lactic acid concentration in the blood. The question how strong this connection is and to what extent individual differences in the intensity of the perception of exertion may be explained with the aid of variation in the lactic acid content, is naturally beyond the scope of this work. The great group differences reported by HOLMGREN & STRÖM seem to offer good possibilities of differential investigations and comparisons of subjective exertion and the lactic acid content in the blood.

Discussion

In order to illuminate an important field, viz. the psychophysical one, the discussion will be limited to two different physiological parameters only. As both these parameters are considered extremely important for the perception of fatigue and exertion during work on the cycle ergometer, the found relations should also be borne in mind as they are of factual interest.

The variation in the intensity of the perception appears to follow a curve between the pulse and lactic acid curves. A closer investigation of the psychophysiological connection with physical work may perhaps explain the differences in psychophysical relations, in work periods of varying length, or for different individuals. The physiological parameters, loaded with different weights, constitute the "gestalting" of the intensity of the perception according to the type of work and to the individual's special way of reacting. Naturally, other physiological parameters should be studied influencing the total perception of exertion and fatigue, and attention should also be paid to their interaction.

Of the two equations mentioned above, the latter, proposed by the present author, gives the most general expression of the power function. It may be applicable to several biophysical relations including psychophysical ones. In symbols of parameters we write:

$$\psi=\psi_0+k\ (\Phi-\Phi_0)^n,$$

where ψ is the intensity of the physiological or psychological reaction, ψ_0 a corresponding basic intensity level, k a measure constant, Φ the intensity of the stimulus and Φ_0 a basic intensity level, where the curve starts to accelerate.

In Chapter II we proposed a method for making interindividual comparisons by using the range from an "absolute" to a "terminal" threshold as a frame of reference. A corresponding method may also be useful when evaluating the significance of a pulse value for physical work. The pulse rate scale is of course no ratio scale. Interindividually speaking it is not even an ordinal scale but may be used as such for rough comparisons. From an interindividual point of view the pulse-scale may, however, be considered an interval scale, so the possibilities for interindividual comparisons according to the above-mentioned principles should be good.

V. THE PSYCHOPHYSICS OF MUSCULAR WORK AND ADJACENT FIELDS

Introduction

These investigations have dealt chiefly with the more general psychological or differential psychological relations in normal individuals. The psychophysical functions in relation to pathological reactions are also of interest. To this group belong *e.g.* important medical cases such as performance and perception disturbances in individuals suffering from various disorders, such as heart or mental diseases.

Related to the psychophysics of muscular work are such odonto-psychological problems as are integrated with the perception of bite-force or bite-pressure, and the adaptation to new chewing conditions.

The interindividual comparisons presuppose good agreement between individuals in the use of quantitative linguistic expressions and mathematical concepts. Thus psychophysics enters the field of semantics.

The above fields appear to be important psychophysical bordeareas and investigations into relevant problems are at present being carried out in collaboration with psychiatrists, clinical physiologists and odontological researchers.

Psychophysics and heart diseases

The perception of subjective exertion in a physical work test, which in normal cases appears interindividually to consist of fairly similarly integrated experiences from the skin, muscles, joints, and organs of circulation, may in pathological cases be dominted *e.g.* by certain special experiences of pain. Both qualitatively and quantitatively a combination of experiences may arise so that the total perception "gestalts" itself in a particularly characteristic way for certain pathological cases.

In a lecture delivered before the Swedish Medical Association 1960 a report was given of the investigations by BORG & LINDERHOLM into the perception of physical work in relation to working capacity in certain groups of patients. Patients and healthy persons had been examined during work on the cycle ergometer with a gradually increased load, after which their subjective perception of exertion was assessed according to a 21-graded rating scale. At the same time the pulse frequency, the breathing frequency and the ECG were recorded. It appeared that certain groups of patients, such as those with arterial hypertension and coronary disease, generally rated the exertion of the work in relation to the pulse frequency more highly than those in a reference group.

Constant use of the patient's subjective assessment of the work load seems to provide valuable information supplementing other data in the assessment of the reaction to the work load. A continuation of the study includes further differentiation of certain groups of patients and is also performed with other psychophysical methods.

A case study that also shows how a simple rating scale can be very helpful in the assessment of the physical working capacity of a person suffering from an abnormal heart reaction, has been reported by Borg & Dahlström (V: 1962). A 47-year-old farmer suffered from hypertension and auricular fibrillation. During a routine examination required for obtaining a driver's license he went through a physical work test. If calculated on the basis of the rated exertion the working capacity as kpm/min. was almost four times as great as that calculated on the basis of the pulse-rate. That in this case the former method of calculation gave a better measure of the patient's working capacity was demonstrated by his everyday working performance.

Psychophysics and psychiatry

In certain conditions of mental disease the ability to perceive a performance or performance capacity in an adequate and objective manner, or a change in the latter, may be subject to different disturbances. Manic, depressive, hysteric or psychastenic conditions appear to call for a closer study with the aid of psychophysical work tests. That change in the perception of exertion which normally seems to accompany changes in the performance capacity – according to the model described in Chapter II with interindividual or intraindividual comparisons – may in different conditions of mental disease be disordered in a typical way. If the performance capacity is still the same in the mental patient the subjective relations may deviate in a characteristic manner as a result of a changed subjective assessment or other frame of reference, level of aspiration etc. At the time of writing investigations are in progress including *e.g.* studies of depressions. Judging from preliminary results the psychophysics of

muscular work provide information of diagnostic interest and importance for the evaluation of the effect of the therapy.

Psychophysics and odontology

Psychophysical investigations of perceived force and subjective exertion approach an important odontological field that concerns the relations between the subjectively perceived and the physically recorded bite-pressure. Investigations of bite-pressure, chewing force and chewing capacity are also of psychological interest. The mouth is an extremely important receptor area and an integrated part of the body's conscious area of stimuli which, in cases of radical changes, *e.g.* loss of teeth or adaptation of denture, may give rise to serious mental disorders, even of a psychotic nature.

Psychophysical investigations into bite-force are now being carried out in collaboration with the Dental School and the Psychological Laboratory of the Umeå Medical School. In works by Borg & Wennström (to be published) methods have been worked out for the assessment of the subjective bite-force or bite-pressure and its physical correlates. Ratio methods as well as simple rating methods afford good possibilities for inter- or intraindividual comparisons. Judging from preliminary results the subjective perception of bite-pressure does not seem to follow a positively accelerating function as in muscular force, but instead a slight negatively accelerating one.

Psychophysics and semantics

Problems of fundamental importance for psychophysical research are those concerned with the semantic premisses for quantitative assessments. The linguistic responses given by experimental subjects following physical stimuli may be regarded as revealing an intervening perceptive reality. It is a problem of extreme importance in the interpretation of psychophysical results to what extent the expressions of everyday language and the formulation of mathematical ratios correspond to relevant facts and should be considered indicators of the intervening experience-variable which we aim to study.

A good general agreement between individuals in the use of different quantitative expressions of characterization is naturally a prerequisite for possible interindividual comparisons. This also holds good for the use of numerical symbols as well as for those expressions of characterization which may be used as a basis for a subjective rating scale.

It seems to the present author that a most fascinating field of research viz. *psychophysical semantics* may be opened up thanks to modern psychophysical methods. As relations between intensities of perceptions can be assessed mathematically and the perceptions characterized with everyday expressions of intensity a possibility for *quantitative semantics* arises. The different quantitative linguistic expressions can be fitted into a subjective ratio scale so that exact mathematical relations between them are obtained.

Simultaneously with the ratio scaling experiments in our psychophysical investigations of subjective exertion in cycle work, the subjects had to assess the degree of exertion according to a rating scale. The linguistic expressions corresponding to the different values in the rating scale were then placed in the psychophysical scale for corresponding physical levels, so that absolute relations were obtained between the expressions. The ratio between "light" and "laborious" in the above experiment was = 1:3. "Neither light nor laborious" was about 1/3 of the distance from "light" to "laborious".

The study of quantitative semantics that we have sketched should be extended to the majority of different sense modalities. The corresponding quantitative semantic relations may be employed even in the case of a more general experience, memory, or conceptual continuum.

VI. SUMMARY

I. This investigation deals mainly with problems concerning physical performance and performance capacity in relation to different measures of the subjective perception of exertion. It is partly a general psychophysical study, but differential problems are also investigated in order to suggest a method which makes possible direct interindividual comparisons of perceptions and to obtain a basis in the construction of methods for determining physical working capacity from psychological variables.

In order to obtain a concise definition the perception of exertion for work on the bicycle ergometer is defined operationally in accordance with the given psychophysical method and the instruction: "how heavy it feels to pedal, how great the pedal resistance is" for short-time work, and for work of longer duration: "how laborious it fells to work".

II. The psychophysical experiment started with short-time work (less than one minute) on the bicycle ergometer. The psychophysical power function given by STEVENS and by EKMAN was also found to be valid for the perceptive continuum of force or effort. In the general function: $R = c\ (S+a)^n$ (EKMAN 1959), R is the intensity of the perception, c a constant related to the unit of measurement, S the intensity of the stimulus and a a constant related to the absolute threshold. A positively accelerating function was found with an exponent about $n = 1.6$ and an a-value of about 150 to 200 units.

The psychophysical ratio functions do not make possible immediate interindividual comparisons of the intensity of perception. A method for interindividual scaling has been proposed here, that may serve as a reliable and valid guide. Our solution is based *inter alia* on the assumption that the intensity of an individual's perception is evaluated in relation to his present and previous experiences, *i.e.* to the whole range of intensities as a frame of reference. The perceptive range and the intensity of the perception at the terminal threshold is put equal for all individuals. The psychophysical functions for two different individuals may then be represented in the same diagram and direct interindividual comparisons be made.

For validation of the method an experiment was carried out where

terminal thresholds for muscle strength were determined and where the subjects also had to rate the degree of subjective effort for one and the same submaximal level. The correlation between the ratings for the submaximal level and the terminal thresholds was strongly negative.

A medium intensity level called the "preference level", by which we mean a level that is perceived by the individuals as being just about right or comfortable, appears to be assessable for a number of sense modalities *e.g.* preferred reading light or car-driving speed. In connection with investigations concerning the working capacity of lumber workers, they had to perform preference level adjustments when working on the bicycle ergometer. The physical intensity corresponding to a preferred level in heavy forest work gave significant correlations with the maximal performance for short-time work on the cycle ergometer, CST, with $r=.42$, and with the mean-wage for two years with $r=.35$.

A method has been worked out for assessing maximal strength thresholds in short-time work on the cycle ergometer. The subject has to start from a low power level, *e.g.* 500 kpm/min., and the power is then increased continuously with 50 kpm/min. per second until the subject can no longer pedal or maintain the stipulated speed. The assessments are repeated three (3) times in such a way that the subject has to pedal for about 45 seconds, to pause for 15 seconds, then again to cycle for 45 seconds etc. This "cycling strength test", "CST", is mainly intended to give an indicator of muscle strength and motivation for short-time effort.

An experiment was carried out with the CS-test on a group of 57 lumber workers. The results of the test showed a high reliability coefficient, $r=.96$. The validity of the test expressed as the correlation with wages was also very high with $r=.60$. As the test only takes a few minutes to perform it is also very time-saving.

III. A study of the reliability and validity of an often used work test on the bicycle ergometer has been made. By correlating physiological measures obtained during the course of the test, intratest correlation have been obtained, *e.g.* for pulse rate as high as $r=.98$ and for breathing frequency $r=.95$. Retest-correlations about 8 months later also showed high values, $r=.76$ and $r=.84$ respectively. To get an expression of the validity of the test, results from a skiing competition were correlated with the work test. A validity correlation of $r=.54$ was thus found.

Psychophysical experiments with the methods of ratio estimation and magnitude estimation have been performed in connection with the above mentioned work test. The obtained results showed that the psychophysical function was positively accelerating and that the general power function

could be adopted to the results. The exponent of the function was about $n=1.6$ for an a-value of 200–250 kpm/min. The power function was also expressed in the following way: $R=a+cS^n$. The exponent is of the same size and $a=\frac{1}{2}-\frac{1}{3}$ of the R-value for the lowest level, 300 kpm/min. taken as the unit.

A subjective rating scale has been worked out making possible inter-individual comparisons. In an experiment with 73 male subjects, they went through a work test and at the same time rated the degree of exertion according to the rating scale. The correlation between the pulse values and the ratings for each of the submaximal power levels was about $r=.40$ and for the whole test, including all power levels, the correlation was $r=.85$. The physical working capacity was calculated both according to the power level at pulse 170/min., and to the level at the rating value that corresponded to pulse 170. The coefficient of correlation between the two measures of working capacity was $r=.61$. We have chosen to test the usability of the rating scale on a group of lumber workers. The results of the investigation showed that for a group of 57 lumber workers the wages correlated with the working capacity according to the ratings, PWC_R, $r=.54$ and with the working capacity according to the pulse rate, PWC_{170}, $r=.24$. As several subjects did not reach pulse rates exceeding 150 beats per minute the latter value should be considered less realiable. Consequently a group was chosen from the material that attained a pulse exceeding 150 beats per minute. This group consisted of 33 individuals whose PWC_{170}-values gave a correlation with wages of $r=.44$, while the PWC_R-values did not now correlate as high, but gave the correlation $r=.37$.

By repeating the cycling strength test described above, intermittently with short pauses between the assessments, it may be possible to obtain a work curve where the adaptability of the organs of circulation is of great importance for the level and the form of the curve, in addition to the influence of motivation and muscularity. An experiment has been conducted on the same material of 57 lumber workers previously mentioned. The power was increased with 50 kpm/min. per second, and the subject worked intermittently with 45 seconds' work and 15 seconds' pause between the assessments. 20 assessments were made and pulse rates checked at the end of each assessment. The results of the investigation showed that the mean work curve descends rather abruptly at the beginning from 2,600 power units to an established level of about 2,150 units. After 10 assessments the curve had reached a fairly stabilized level. Already after the first assessments the pulse rate was relatively high or 150 beats per minute. After some assessments it increased to a relatively constant level of about 157—158 units for the mean of the group. A reliability coefficient was calculated on the split-half values which gave a very high coefficient, $r = .997$. The validity of the work curve assessments in the form of correlations between wages and mean values was $r = .65$. As we know that the criterion reliability is rather low, it may be of interest to correct for attenuation. With the criterion reliability $r_{tt} < .80$ a correlation between the test and the criterion of $r > .70$ is obtained.

This study together with the one mentioned above concerning the subjective ratings show that the perception of exertion experienced by a forest worker seems to influence the field performance as much as the working capacity estimated from physiological variables. Beyond the physical working capacity, the resources of "mental energy", the motivation and the ability to tolerate heavy physical strain and stress also seem to be of great importance.

IV. To compare the psychophysical relations to biophysical ones we have made a study of the variation of the pulse rate and the blood lactate concentration. In several investigations it has been found that the pulse rate increases linearly with the power. The following equation may describe the function: $P = b + c \times S$, where P is the pulse at a certain power level, b the basic pulse level, c a measure constant and S the physical power. In one of our experiments the following equation was found: $P = 70 + 8 \times 10^{-2} \times S$, where S is measured in kpm/min.

In the afore-mentioned investigation of subjective rating and pulse reaction, a strong correlation, $r = .83$, was found between subjective ratings and pulse rate during a work test. The variation of individual ratings could thus, to a great extent, be "explained by" the pulse reaction.

In a work by HOLMGREN & STRÖM an account is given of the variation of the lactic acid concentration in the blood in relation to the physical power during work on the cycle ergometer. In order to compare our psychophysical functions with that function which the lactic acid concentration describes in relation to the power, we made a rough interpretation of the results in terms of a biophysical equation. For a rather "normal group" the following equation was obtained: $L = 13 + 7 \times 10^{-6} \times S^{2.2}$, where L is the lactic acid concentration at a certain power level, and S the physical power in kpm/min. For a group of racing cyclists we had to add an S_0-value, *i.e.* a power value where the curve begins to accelerate. This leads to the following most general expression of a power function:

$$\psi = \psi_0 + k\,(\Phi - \Phi_0)^n,$$

where ψ is the intensity of the physiological or psychological reaction, ψ_0 a corresponding basic intensity level, k a measure constant, Φ the intensity of the stimulus and Φ_0 a basic intensity level, where the curve starts to accelerate. This general expression may be applicable to several biophysical relations on the whole including psychophysical ones.

V. Investigations carried out and still in progress by BORG & LINDERHOLM on the perception of physical work in relation to working capacity in certain groups of patients, have shown that those with hypertonia and coronary diseases generally rate the exertion of the work in relation to the pulse frequency greater than those in a reference group. A case study by BORG & DAHLSTRÖM is also reported, where a 47-year old farmer with hypertension and auricular fibrillation went through a physical work test. If calculated on the basis of the rated exertion the working capacity as kpm/min. was almost four times as great as that calculated on the basis of the pulse rate. That in this case the former method of calculation gave a better measure of the patient's working capacity was demonstrated by his every-day working performance.

Problems of fundamental importance to psychophysical research are those concerning the semantic premises for quantitative assessments. To what extend the expressions of everyday language and the formulation of mathematical ratios correspond to relevant facts and should be considered indicators of the intervening experience variable, which we aim to study, are problems of extreme importance when interpreting psychophysical results. Thanks to modern psychophysical methods it seems to the present author that a most fascinating field of research may be opened up, viz. psychophysical semantics. As relations between intensities of perceptions can be assessed mathematically, and the perceptions also characterized by every-day expressions of intensity, a possibility for quantitative semantics arise.

In one psychophysical investigation of subjective exertion in cycle work, simultaneously with the ratio scaling experiments, the subjects had to assess the degree of exertion according to a rating scale. The linguistic expressions that corresponded to the different values in the rating scale, were then for corresponding physical levels placed in the psychophysical scale so that mathematical relations were obtained between the expressions. The ratio between "light" and "laborious" in the above experiment was: 1 : 3. "Neither light nor laborious" lay about 1/3 of the distance from "light" to "laborious". It seems that this study into quantitative semantics may be extended to the majority of different sense modalities.

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