REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY
THE UNIVERSITY OF STOCKHOLM

ANNUAL REPORT

I

1970

ANNUAL REPORT 1970

This report presents abstracts of papers reporting the research work of the Institute of Applied Psychology of the University of Stockholm. The first part of the report includes abstracts of works published in international journals and books. In the second and third parts, abstracts of papers are presented which appeared in the series "Reports from the Institute of Applied Psychology" and in other report series.

The research work reported here was mainly supported by grants from the Swedish Council for Social Science Research and the Tercentenary Fund of the Bank of Sweden.

This report presents only abstracts of articles published in English or other international languages.

PUBLICATIONS IN INTERNATIONAL JOURNALS AND BOOKS

Borg, G. Perceived exertion as an indicator of somatic stress. Scandinavian Journal of Rehabilitation Medicine, 1970, 2, 92-98.

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

Borg, G., and Linderholm, H. Exercise performance and perceived exertion in patients with coronary insufficiency, arterial hypertension and vasoregulatory asthenia. Acta Medica Scandinavica, 1970, 187, 17-26.

A standardized work test has been performed by healthy subjects, patients with coronary heart disease, patients with arterial hypertension, and with the vasoregulatory asthenia syndrome. Heart frequency and rating of perceived exertion according to a rating method were assessed at various work loads. Different measures of physical working capacity were estimated. Patients with vasoregulatory asthenia - and patients with arterial hypertension, although less markedly - rated the exertion to be less in relation to heart frequency than healthy controls, particularly at low rating levels. On the contrary, patients with coronary heart disease rated the exertion to be higher, particularly at high ratings, in relation to heart frequency. In all patient groups studied, there was a smaller mean increase in heart rate in relation to a given increase in rating of exertion, i.e. for a given increase in heart rate there was a greater increase in rating of exertion than in healthy controls. Submaximal measures of physical working capacity were based on heart rate and rating of perceived exertion. The ratio between measurements of physical working capacity based on heart rate and those based on rating of perceived

exertion was low in the VA group and high in patients with coronary insufficiency when compared with controls of equal age. Patients with a low "maximal" performance during the test also had a low submaximal physical working capacity estimated from heart frequency as well as from rating of perceived exertion. The difference found between the various patient groups, especially that between patients with coronary heart disease and patients with the vasoregulatory asthenia syndrome is of differential diagnostic value.

Kronlund, J. Evaluation of technical aids. In: Prosthetic and Orthotic Practice (Ed.: G. Murdoch). London, 1970.

PAPERS PUBLISHED IN THE REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY, THE UNIVERSITY OF STOCKHOLM

Borg, G. Relative response and stimulus scales. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 1.

In psychology and physiology there is a need for a theory concerning interprocess comparisons. In some cases, e.g. when making interindividual comparisons between perceptual magnitudes, it is impossible or not meaningful to convert raw scores to a standard scale by using the standard deviation as the unit of measurement. A theory is therefore presented which introduces the range of possible responses as a frame of reference. On the basis of the range and the stimulus-respons function in question relative response and stimulus scales are constructed for interindividual and other kinds of interprocess comparisons. The validity of the theory is tested by comparing correlations between variables with and without correction according to the theory. Abundant empirical evidence is presented in favour of the assumptions.

Borg, G., Bratfisch, O., and Dornic, S. On perceived difficulty. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 10.

The development and meaning of the concept of "perceived difficulty" is being described with special regard to the differences between physical and mental work. The main results of experiments carried out so far are presented. A substantial part of the paper is devoted to the analysis of the concept of perceived difficulty and to the problems and possibilities of measurement. The concept of perceived difficulty is dealt with also in a differential connection and a model for interindividual comparisons is suggested. It is emphasized that a systematic investigation of perceived difficulty is both possible and useful, and that it yields an opportunity to improve and facilitate the construction of psychological tests. Finally, possible future research projects are briefly outlined.

Borg, G., Edgren, B., and Marklund, G. A flexible work test with a feedback system guiding the test course. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 8.

A flexible work test is presented. Its purpose is to give a behavioural measurement of physical working capacity in the form of the highest work load on which a subjects is able to work for 4 min (W^4_{max}). The test is designed to

have all subjects work for the same duration on a series of subjectively equal work loads. For practical and administrative reasons the test should be kept short - about 10 min - and the initial work load fairly high. To meet this requirement the test is divided into two main parts (initial and final work periods) and a feedback system based on physiological and psychological stress indicators is constructed to guide the test course. The flexible work test is applied to a bicycle ergometer and tested on a small group of soldiers. The results indicated the possibility of designing a test according to the principles proposed.

Borg, G., Edström, C.-G., and Marklund, G. A new method to determine the exponent for perceived force in physical work. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 4.

A new method for psychophysical scaling has been applied in an experiment concerning perceived force (perceived pedal resistance) for work on a bicycle ergometer. The stimulus intensity was varied as a function of time and the subject's task was to report how he perceived the variation. The method with stimulus variation as a function of time is combined with a classical psychophysical method for threshold determinations. When the work load increased as the 0.4 or decreased as the 0.6 power of time the variation was judged to be linear. The exponents of the corresponding psychophysical functions are 2.3 and 1.6.

Borg, G., and Hosman, J. The metric properties of adverbs. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 7.

The ratio properties of the following verbal expressions were investigated: very long, rather long, neither long nor short, rather short, very short. It could be demonstrated that the relation between pairs of these expressions was approximately invariant with change of experimental conditions. This supports the hypothesis that adverbial intensives serve as multipliers. The results suggest the possibility of erecting ratio scales by verbal scaling methods.

Bratfisch, O. Time-estimations of the main activities of university students. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 2.

On each day of one week a group of 32 university students of mathematics were given a questionnaire and asked to report what kind of activities they were occupied with the day before and to express, in minutes, how much time they had spent on each of the activities. In another part

of the investigation the same subjects were instructed to estimate the relation between main activities, sampled from the questionnaire, with regard to the time they devoted to the various activities on the average. When relating these two kinds of time-measures - answers to the questionnaire being regarded as "objective" data, estimations being considered as subjective measures - it was found that subjects overstimated certain activities while they underestimated other ones. Periods of rest and sleep as well as time spent on amusement activities were underestimated while the time devoted to studies was strikingly overestimated. - A possible application of time-measures of this kind in applied psychology is discussed.

Bratfisch, O., Dornic, S., and Borg, G. Perceived difficulty of a motor-skill task as a function of training. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 11.

A simple "wire labyrinth" was used in an experiment involving learning of a two-hand motor task. The Ss were asked, after completing each of 7 successive trials, to give their estimates of perceived (subjective) difficulty of the task. For this purpose, the psychophysical method of magnitude estimation was used. Time was measured as a criterion of performance. The sevenfold repetition of the task resulted in a drop of performance time from 61 secs to 35 secs, i.e., by about 43 %, while the perceived difficulty decreased from the initial value of 10 to 5.2, i.e., by 48 %. The course of both functions was fairly similar; the correlation coefficient of 0.96 showed a close relationship between perceived difficulty and time. It is suggested that, in the task employed, the estimation of difficulty was mainly based on the perception of time.

Dornic, S., Bratfisch, O., and Santesson, A. Verbal factor in immediate memory. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 14.

Messages consisting of increasing number of digits were presented acoustically at a rate of one digit per 0.75 sec. In the first condition (Forward recall), the Ss' task was to recall the messages in the original order; in the other condition (Backward recall), they had to recall the digits in the reversed order. Thirteen Swedish subjects with a fluent knowledge of English participated in the experiment. The messages were presented both in the Ss' mother tongue and in English. The data obtained showed the recall to be significantly better with messages presented in the Ss' dominant language, the difference being greater with regard to the criterion of "order information" than that of "item information". The results are interpreted in terms of differences in coding capacity between the dominant and nondominant languages.

Dornic, S., Künnapas, T., and Bratfisch, O. Subjective similarity as a function of exposure time and short term memory. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 9.

Two experiments were carried out to verify the usability of the method of similarity estimation in the area of perception and short term memory. In the first experiment, pairs of simple visual stimuli were exposed for different time periods which ranged from 1 to 20 msecs. Similarity was found to decrease with increasing exposure time. In the second experiment, the Ss' task was to compare the similarity of the first and last stimulus in a series of 7 different figures. Exposure time of 300 msec was used in order to rule out any errors on the perceptual level. The whole series was repeated 5 times. Similarity was found to decrease with repeated presentation of the series, the difference in similarity estimates between the first and the last series being 20 %. Probable mechanisms of the processes involved in the tasks are discussed. It is concluded that the method of similarity estimation is a highly usable measurement tool in investigations concerning visual discrimination and short term memory.

Hosman, J. The factor structure of magnitude productions. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 5.

The hypothesis was tested that number matching is an intermediate step in cross-modal equal ratio setting. Three continua (duration, length of line and fingerspan) were scaled with the method of magnitude production. The intercorrelations between the logarithmically transformed magnitude productions were factoranalyzed and rotated to simple structure. The factor structure of magnitude productions turned out to be highly similar to that of cross-modal equal ratio settings. This result did not give evidence in favor of the hypothesis.

Hosman, J. The dimensionality of cross-modality matches. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 6.

Four standard continua (white noise, duration, grayness and area) were scaled by two variable continua (length of line and fingerspan), using the method of cross-modality matching. The logarithmically transformed, standardized estimates were subjected to factor analysis in order to compare the factor structure of cross-modal matches with that of free numerical assignments. It turned out that the factor matrices obtained under both conditions of scaling are highly similar. This lends support to the hypothesis that "anchoring on end-stimuli" is not specific for the method of free numerical assignment, but is a general

characteristic of scaling methods where the subject is free to specify his own unit of measurement.

Hosman, J. The dimensionality of direct estimates. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, Supplement 1.

A testable hypothesis concerning the dimensionality of logarithmically transformed magnitude estimates was derived assuming the validity of Stevens' power law, $\log R = \log c_i + n_i \log S$, at the individual level. The hypothesis was put to empirical test by analyzing the dimensionality of 27 correlation matrices computed over magnitude estimates. The hypothesis could be rejected convincingly. In all cases the rank of the correlation matrices was three instead of the hypothesized unit rank. In order to explain this result two hypotheses were formulated: One hypothesis stated that the three dimensions were due to the way in which subjects handle numbers, the other hypothesis stated that the dimensions represented genuine perceptual factors. These hypotheses were tested by analyzing the rank of 27 correlation matrices computed over cross-modality matches where number matching was assumed not to occur. Again, it was found that the rank of all matrices was approximately three. Although these results favored the perception hypothesis, it could not be excluded that number matching had taken place whenever subjects matched intensities to criterion stimuli. Therefore, the rank of nine correlation matrices computed over magnitude productions was determined. Also, these matrices were of about rank three. Since the rank problem could not be solved by experimental methods, the scaling behavior of individual subjects was studied by simulation experiments. Several models were formulated and tested. It turned out that empirical scaling behavior could be simulated successfully by assuming that subjects differ by individual psychophysical exponents, choose, contrary to the instructions, their own unit of measurement and overestimate stimuli smaller than the standard and underestimate stimuli larger than the standard.

Hosman, J., and Borg, G. The mean and standard deviation of cross-modality matches: A study of individual scaling behavior. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 3.

The variability of repeated cross-modality matchings to a series of stimuli was analysed. Two hypotheses were formulated: (1) The variability arises from different units of measurement over replications, (2) the variability arises from different exponents over replications. From both hypotheses testable deductions were made. A crucial experiment gave abundant experimental evidence in favor of the first hypothesis.

Hosman, J., and Borg, G. The metric structure of verbal expressions: a further investigation. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 12.

The metric properties of the adverbs: unusually, quite, very, pretty, rather, somewhat and slightly were investigated by pairing them with the adjectives long and short. The subjective intensities corresponding to the verbal expressions were measured with the method of equal ratio setting using length of line as matching continuum. The scale values for the verbal expressions were invariant up to a constant of proportionality under change of experimental conditions indicating that verbal expressions are measureable on a ratio scale. The variability of the individual scale values varied with experimental conditions. It turned out that the frame of reference has a decisive influence on the degree of preciseness with which verbal expressions are used.

Valter, V. Deduction and verification of a quantum psychophysical equation. Reports from the Institute of Applied Psychology, The University of Stockholm, 1970, No. 13.

Assuming sensitivity of the senses to decrease uniformly towards the lower and upper thresholds from the standpoint of a fictive continuum of a scale set up on the basic sensitivity which they have at middle stimulus levels, the present author has succeeded in deducing a difference equation which relates to the fundamental problem in psychophysics, and which he characterised as a "quantum psychophysical equation":

$$r' = r + r\,(\alpha\, r^{-\kappa} + \beta + \gamma r^{\theta})$$

The equation determines a set of pairs of stimulus levels r and r′, where r<r′, between which an equal and, in a special case, a liminal subjective contrast appears. The remaining members of the equations are constants which have to be determined empirically for the given sense modality, experimental situation, selected subjective contrast and object of measurement; the latter may be either man, animal, or in a certain sense also plants. After a formal adjustment the equation may be used to express the course of Weber's fraction within the lower and upper thresholds. The equation was verified on many classical and contemporary studies by several authors.

PAPERS PUBLISHED IN OTHER REPORT SERIES

Bratfisch, O., Ekman, G., Lundberg, U., and Krüger, K. Subjective temporal distance and emotional involvement. Reports from the Psychological Laboratories, The University of Stockholm, 1970, No. 299.

Three experiments were conducted in which subjects were required to estimate the subjective temporal distances of various historical periods, each of which was named after some person, event, or social process. In all, 65 subjects participated. In related experiments the same subjects estimated their degree of emotional involvement in what might have happened to people living during the various periods named. Using the actual dates when the events took place, the relation between objective and subjective temporal distance was found to be described by a simple power function. Emotional involvement was shown to be inversely related in a simple monotonic manner to both subjective and objective temporal distance, when other variables were so far as possible held constant. A number of different alternative power functions as well as an exponential and a logarithmic function were fitted to the empirical data. A specific type of power function with three empirical constants and a simple exponential function were found to describe experimental data to a good approximation.

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PUBLICATIONS IN INTERNATIONAL JOURNALS AND BOOKS

Borg, G. Psychological and physiological studies of physical work. In: Measurement of Man at Work (Eds.: W.T. Singleton, J.G. Fox, & D. Whitfield). London: Taylor & Francis, 1971.

A review is given of research performed during twelve years on psychological problems in physical work. The review is presented as a chapter in a book on problems concerning human factors engineering and deals with the "subjective costs" of hard physical work in the form of measurement of perceived exertion and subjective force. Furthemore problems concerning performance indicators of physical stress and working capacity are dealt with.

Borg, G. The perception of physical performance. In: Frontiers of fitness (Ed.: R.J. Shephard). Springfield, Illinois: Thomas, 1971.

Empirical studies and theoretical discussions are presented on perceived exertion, working capacity, motivation and performance. The "subjective costs" behind hard work are studied, and behavior measures of physical working capacity as well as quantitative evaluation of the degree of work motivation behind physical achievements are dealt with.

Borg, G. Studies in the psychology of hard muscular work. Studia Psychologica (Bratislava), 1971, 13, 18-22.

A review is given of work done by the present author and his collaborators on the psychophysics of perceived force and exertion, on behavior test of physical working capacity, on a theory for interindividual comparisons of perceptive intensities and other interprocess comparisons, such as those between modalities and disciplines (e.g. between ratings of perceived exertion, heart rates and blood pressure values as different indicaters of physical stress). Further studies have been performed on clinical and other applied problems of the "subjective tests" of an individual as a complement to the psychological and performance measurements, on a new bicycle ergometer, on a model for the quantitative evaluation of work motivation and on some related studies in the psychology and psychophysiology of physical work.

Borg, G. La sensation de fatigue consécutive au travail physique. Psychologie Médicale, 1971, 3, 761-773.

The article deals with theoretical questions concerning methods for measuring subjective exertion and fatigue, as well as with several studies and applications in medicine, sport and ergonomics.

Borg, G., Bratfisch, O., and Dornic, S. On the problems of perceived difficulty. Scandinavian Journal of Psychology, 1971, 12, 249-260.

The development and meaning of the concept of "perceived difficulty" is presented. A concise survey of experiments carried out so far is given with regard to the main theoretical, methodological and applied problems at which the investigations aimed. A substantial part of the paper is devoted to the analysis of the concept of perceived difficulty and to the possibilities of measurement. The concept of perceived difficulty is dealt with also in a differential connection and a model for interindividual comparisons is suggested. It is emphasized that a systematic investigation of perceived difficulty is both possible and useful, and that it yields an opportunity to improve and facilitate the construction of psychological tests. Finally, possible future research projects are briefly outlined.

Bratfisch, O., Ekman, G., Lundberg, U., & Krüger, K. Subjective temporal distance and emotional involvement. Scandinavian Journal of Psychology, 1971, 12, 147-160.

Three experiments were conducted in which subjects were required to estimate the subjective temporal distances of various historical periods, each of which was named after some person, event, or social process. In all, 65 subjects participated. In related experiments the same subjects estimated their degree of emotional involvement in what might have happened to people living during the various periods named. Using the actual dates when the events took place, the relation between objective and subjective temporal distance was found to be described by a simple power function. Emotional involvement was shown to be inversely related in a simple monotonic manner to both subjective and objective temporal distance, when other variables were so far as possible held constant. A number of different alternative power functions as well as an exponential and a logarithmic function were fitted to the empirical data. A specific type of power function with three empirical constants and a simple exponential function were found to describe experimental data to a good approximation.

Hosman, J. The factor structure of magnitude productions. Studia Psychologica, 1971, 13, 48-52.

The hypothesis was tested that number matching is an intermediate step in cross-modal equal ratio setting. Three continua (duration, length of line and fingerspan) were scaled with the method of magnitude production. The intercorrelations between the logarithmically transformed magnitude productions were factoranalyzed and rotated to simple structure. The factor structure of magnitude productions turned out to be highly similar to that of cross-modal equal ratio settings. This result did not give evidence in favor of the hypothesis.

PAPERS PUBLISHED IN THE REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY, THE UNIVERSITY OF STOCKHOLM

Borg, G. A note on a "dispersion method" in psychophysical scaling. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 17.

A psychophysical "ratio scaling" method is proposed where numerical estimates are avoided. The method, called "the dispersion method", utilizes the dispersion and the degree of skewness of produced "equal setting" data for a rough estimation of the size of the exponent of the power function.

Borg, G., Bratfisch, O., and Dornic, S. Perceived difficulty of an immediate memory task. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 15.

Two experiments were performed using messages of digits presented auditorily at a rate of two digits per sec. In both experiments, messages of seven different lengths were employed, consisting of 4 to 10 digits in Experiment 1, and of 2 to 8 digits in Experiment 2. The Ss were asked to recall them in the original order, and then to estimate the difficulty of the task by means of the method of magnitude estimation. Messages were presented in pairs of different length, the first message in each pair serving as standard for estimating the difficulty of the other message. All pairs were presented twice. In Experiment 1, perceived difficulty was found to be an exponential function of message length. Ss with a higher immediate memory span gave lower estimates for the longest messages than Ss with a lower span. In Experiment 2, the relation between perceived difficulty and message length appeared to be linear. It is argued that with shorter messages, estimates of difficulty were probably affected by the stimulus variable, while with longer messages, the response variable (recall) might have been decisive for the perception of difficulty.

Borg, G., Bratfisch, O., and Dornic, S. Perceived difficulty of a visual search task. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 16.

An experiment was carried out on perceived difficulty of a simple attention task. Seven complex stimulus matrices were used, consisting of different number of pairs of consonants. The Ss' task was to search for targets determined by the experimenter one by one. Search time was measured as performance criterion. Perceived difficulty of the task was measured by the method of magnitude estimation, one of the matrices serving as standard. The

results showed perceived difficulty to be a negatively accelerated function of both stimulus and response variables involved. It appears probable that the estimates of difficulty were contaminated by the structure and size of the visual field, particularly by the estimation of numerousness. It is concluded that isolation of the perception and, hence, of the estimation of difficulty is an important methodological problem in the area under study.

Borg, G., Cavallin, N., Edström, C.-G., and Marklund, G. Motivation and physical performance: Two experiments on monetary reward. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 19.

The aim of the present paper was partly to give a short theoretical and empirical background concerning motivation, reward, and performance and to present a simple model for quantitative analysis of work motivation, and partly to report two pilot studies on the effects of monetary reward on motivation-loaded maximal performance on the bicycle ergometer. The results of the first experiment showed that motivation-loaded maximal performance (approx. 45 seconds each) increased with increased reward and that this effect was positively related to monetary need, as measured with a behavioural indicator. The results of the second experiment indicated that the change of performance with the amount of monetary reward follows a negatively accelerating course. A negatively accelerating course was also obtained for the performance change with the number of trials when a constant reward was given. Assumptions of an "elation" effect when rewards were given in an increasing order and of a "depression" effect when given in a decreasing order were not supported. The assumption of a lower performance at a very small monetary reward, compared to an unrewarded performance, was not supported either.

Borg, G., Edgren, B., and Marklund, G. A simple walk test of physical working capacity. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 18.

A pilot validation study of a simple walk test indicating working capacity is presented. The main prerequisites for the test were: a high degree of simplicity, a safe test situation, a minimum of technical equipments and a nice test situation. Through instructions two different walking speeds were induced to each subject and the speed was determined only by the subject's own perception. The pulse rate and the rating of perceived exertion were used as stress indicators. The indicator of

working capacity was defined as the walking speed at a certain reference level in pulse rate and/or rating of perceived exertion. For validation a bicycle ergometer test of submaximal character was used. 16 females and 10 males took part in the study. The groups were heterogeneous in many respects. For the males the correlation between the walk and bicycle test was .75. For the females the same correlation was .13. The results indicated that the females probably interpreted the instructions differently than the males. Further studies concerning the implications of different instructions, the conditions for "steady-state", the reliability and the validity are suggested.

Borg, G., Edström, C.-G., and Marklund, G. A bicycle ergometer for physiological and psychological studies. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 24.

This paper presents a new bicycle ergometer. The bicycle is designed to meet those demands which are likely to be made on a bicycle ergometer that may be used for different purposes. The power ceiling is high enough for measurements, not only of endurance capacity but also of muscular strength. The construction of the ergometer also makes measurements of work motivation possible. By means of a reliable automatic device, the work load can be increased (or decreased) linearly (or according to some other suitable function) with the pedalling time. The bicycle ergometer presented here has proved highly efficient and adaptable and this would seem to indicate good opportunities for application in a number of clinical, military and sporting fields.

Bratfisch, O. A further study on subjective and objective intelligence factors. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 20.

Forty-three highschool students participated in a laboratory experiment involving estimation of qualitative similarity between items sampled from ten conventional tests of intellectual performance. Estimated similarity could tentatively be described as a function of positive inter-test correlation as determined from another group of 123 individuals with the same level of education. The similarity matrix was treated as in multidimensional psychophysics, test items being regarded as stimuli. Five "subjective" factors were found, corresponding to the "objective" performance factors extracted from analyses of the correlational data. The results confirm the findings of a previous study by Bratfisch and Ekman.

Dornic, S., and Borg, G. Visual search for simple geometric figures: the effect of target - noise similarity. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 22.

The influence of similarity between target and noise stimuli was studied on the detectability of simple geometric figures in complex visual fields. Eighteen different display were used, each consisting of 49 figures. Ten different figures were employed, six of them serving alternately as targets. The displays were repeatedly projected on a screen, each exposure lasting 0.2 sec. The Ss' task was to locate the targets as quickly as possible. Number of necessary exposures served as performance score. Subjective similarity between figures was measured by the psychophysical method of similarity estimation. - The detectability of the targets was found to depend predominantly on the degree of similarity (confusability) between the target and the noise stimuli, particularly those situated close to the target. The circle had the lowest overall similarity index, and was the easiest to detect. The square had the highest similarity index and the lowest detectability score. No systematic effect of the information content of the target figures was found.

Hosman, J. The effect of randomizing the starting point of cross-modal matches. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 21.

Three standard continua, grayness (G), heaviness (W) and area (S) were scaled by each of the following variable continua, length of line (L), force of hadgrip (Fo) and fingerspan (Fi) using the method of cross-modality matching. The hypothesis was tested that assimilation on endstimuli could be reduced by randomizing the starting point of the cross-modal matches. The experimental results supported the hypothesis.

Hosman, J. The distribution of individual cross-modality matches. Reports from the Institute of Applied Psychology, The University of Stockholm, 1971, No. 23.

The distribution of individual cross-modality matches was investigated. Ten subjects made 500 matches of length of line to each of five criterion stimuli from the continuum of fingerspan and the continuum of darkness. It could be demonstrated that matches to fingerspan were log-normally distributed though exceptions existed. Matches to darkness were neither normally nor log-normally distributed.

PAPERS PUBLISHED IN OTHER REPORT SERIES

Bratfisch, O., and Lundberg, U. Subjective distance and emotional involvement: experimental validation of the inverse square root law. Reports from the Psychological Laboratories, The University of Stockholm, 1971, No. 332.

Two groups of Swedish subjects and one group of Austrian subjects were instructed to estimate, in three separate experiments, a number of different inter-city distances with Stockholm as the center in the first two and Vienna in the latter one. In another part of the experiments the same subjects estimated the degree of emotional involvement that they would experience in things assumed to take place in the various cities. A simple power function was found to describe the relation between emotional involvement and subjective distance and in all experiments the exponents turned out to be very close to -0.50, when other factors were kept constant. Thus, the "inverse square root law", found in a number of previous studies, was supported and also validated from a cross-national point of view.

Dornic, S., Myrsten, A.-L., and Frankenhaeuser, M. Effect of alcohol on short-term memory. Reports from the Psychological Laboratories, The University of Stockholm, 1971, No. 336.

Four memory tasks were employed differing in interference and in retention interval: (1) immediate forward recall and (2) immediate backward recall of acoustic and visual messages of digits, (3) delayed recall of consonant trigrams, and (4) delayed recall of visual symbols used in a search task. Eight healthy male subjects participated in the experiments. A series of different criteria were used to analyse the data. Performance under the influence of alcohol was found to be somewhat impaired in all four tasks, the difference being more pronounced in visual than in auditory tasks. In immediate memory span order-information storage was less affected than item-information storage. It is suggested that this difference might be associated with a greater resistance to alcohol of mechanical coding as compared with higher storage processes.

Lundberg, U., Bratfisch, O., and Ekman, G. Emotional involvement and subjective distance: a summing up of the experiments and a final test of the inverse square root law. Reports from the Psychological Laboratories, The University of Stockholm, 1971, No. 334.

Data from eight previous experiments, in which the relation between emotional involvement and subjective geographic distance could be described by the "inverse

square root law", were treated together in the present study. It was found that the combined data formed a clear and simple trend which also was described by the "inverse square root law". However, a small but systematic deviation from the fitted function could be observed. The relation between emotional involvement and objective geographic distance, as well as the relation between subjective and objective geographic distance showed a large scatter in the data around the fitted functions. The results were interpreted as an illustration of the importance of investigating psychological phenomena on the proper, i.e. the psychological, level.

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PUBLICATIONS IN INTERNATIONAL JOURNALS AND BOOKS

Bar-Or, O., Skinner, J. S., Buskirk, E. R., Borg. G. Physiological and perceptual indicators of physical stress in 41-to 60 year-old men who vary in conditioning level and in body fatness. Medicine and Science in Sports, 1972, 4, 2, 96-100.

Perceived exertion during exercise was studied in 51 physically active and in 19 sedentary men, 41-60 years old, by the use of a numerical scale for rating of perceived exertion (RPE). The subjects, who varied in degree of adiposity, each had two or more characteristics associated with the possible development of coronary heart disease.

Each man was given a graded bicycle ride and a graded treadmill walk, up to a heart rate (HR) of 150 beats/min. HR, systolic blood pressure, and RPE were determined at each load. The work levels at which HR was 150 and 130 were calculated, as well as the load preferred by each subject for a hypothetical 15 min exercise bout, and the anticipated HR at this load.

The following conclusions are suggested: (1) RPE is closely related to the submaximal HR, and therefore to the relative work load, irrespective of conditioning or adiposity. (2) The treadmill has some advantages over the bicycle as an ergometer for perceptual, as well as physiological studies, when direct comparisons of subjects of different body weights and composition are to be done. (3) 41-60 year old men of the type studied prefer to cycle or walk at about 50 percent of their estimated maximal work capacity.

Dornič, S. Order error in attended and nonattended tasks. In: S. Kornblum (Ed.): Attention and Performance IV, New York: Academic Press, 1972, p. 119-125.

Order errors were studied in the recall of a memory task (auditory messages) presented under different conditions, in which the subjects (a) attended to a tracking task during the presentation of the messages, or (b) attended to the messages themselves. No significant difference was found between these conditions in the percentage of correct message with the correct order of items. The percentage of correct messages with a wrong order was, however, significantly lower when the subjects did not attend to the presentation of the memory task. The results are interpreted as being due to the fact that the retention of item information in the recall of nonattended tasks is probably bound to the retention of order information.

Henriksson, J., Knuttgen, H. G., Bonde-Petersen, F. Perceived Exertion during Exercise with Concentric and Eccentric Muscle Contractions. Department of Physiology, Gymnastik- och idrottshögskolan, Institute of Applied Psychology, University of Stockholm, Sweden. Ergonomics, 1972, Vol. 15, No. 5, 537-544.

The perception of exertion was studied with special reference to oxygen consumption and heart rate under two exercise conditions, namely with concentric (shortening) and eccentric (lengthening) muscle contractions. Exercise was performed on a Krogh cycle ergometer adapted for the two types of exercise. Oxygen consumption was determined by Douglas bag-Haldane technique, heart rate by ECG, and perceived exertion by a rating scale. Eccentric exercise was perceived as requiring less exertion compared to concentric exercise at similar intensities. When compared on the basis of equal oxygen consumption and heart rate, eccentric exercise was perceived as requiring greater exertion. Exercise at lower rpm was perceived as requiring greater exertion in both forms of exercise as opposed to exercise at higher rpm. It is suggested that exertion during various forms of exercise and under different conditions is perceived or assessed from different combinations of information obtained from afferent and efferent signals.

Lundberg, U., Bratfisch, O., Ekman, G. Emotional involvement and subjective distance: a summary of investigations. The Journal of Social Psychology, 1972, 87, 168-177.

Data from eight previous investigations, in which the relation between emotional involvement and subjective geographic distance could be described by the "inverse square root law", were treated together in the present study. It was found that the combined data formed a clear and simple trend which also was described by the "inverse square root law". However, a small but systematic deviation from the fitted function could be observed. The relation between emotional involvement and objective geographic distance, as well as the relation between subjective and objective geographic distance, showed a large scatter in the data around the fitted functions. The results were interpreted as an illustration of the importance of investigating psychological phenomena on the proper -i.e. the psychological level.

PAPERS PUBLISHED IN THE REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY, THE UNIVERSITY OF STOCKHOLM

Borg, G. A ratio scaling method for interindividual comparisons. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 27.

A psychological ratio scaling method is presented making possible direct interindividual comparisons of perceptual intensities. An experimental study is reported concerning perceived exertion during work on a bicycle ergometer. At the same time as psychological estimates, measurements of physical stress were recorded in the form of heart rate. High correlation was obtained between heart rate and perceived exertion demonstrating the validity of the method. The study also showed that no advantage was gained by using individual exponents rather than a general exponent.

Borg, G. On the importance of range differences on psychophysical functions. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 31.

A review of some psychophysical and physiological studies that elicit the importance of range differences for interprocess comparisons is presented. The method for comparisons starts from the assumption of subjective equality in the intensities of perceptions at terminal levels and subjective equality of ranges. With the assumption of intersubjective constancy, measure constants can be solved for each individual, thus permitting interindividual comparisons. This has been validated in psychophysical studies of hard muscular work. In a study of "intermodal" comparisons of taste qualities the true differences in effective stimulus ranges were directly related to the differences in exponents.

Borg, G. The basic "noise constant" in the psychophysical function of perceived exertion. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 33.

The psychophysical function of perceived exertion (R) for work on a bicycle ergometer has been described by the following power function:

$$R = a + cS^{1.6},$$

where S is measured in kpm/min (or Watt) and the a-constant is of the size of 1/3 - 1/4 of the magnitude of the R-value at S = 300 kpm/min (or 50 Watt). In most of our earlier studies the inclusion of the a-constant has given a better linearity in the log-log plot. In this study empirical support has been obtained for a "basic

perceptual noise constant". Direct estimates of perceived exertion before and after work give a positive a-value of the same size as the one earlier obtained just to improve the linearity in double-logarithmic scales. The idea of estimating the starting point of a psychophysical function from determinations of an absolute threshold and differential thresholds is also put forward.

Borg, G., Edström, C-G., and Marklund, G. Effects of the rate of the work load increase on terminal thresholds for physical work. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 25.

The purpose of the present investigation was to study the transition from short time (mainly anaerobic) work of muscle strength character to prolonged (mainly aerobic) work of endurance character. An experiment was designed to show how measurements of terminal thresholds for physical strength and endurance capacity - determined on the bicycle ergometer - are influenced by the rate of the work load increase and the working time, which is dependent on this. The transition from anaerobic to aerobic work gave characteristic changes in the performance measurements (a falling work curve) and in the simultaneously registered heart frequencies, which increased towards an asymptotic value. Since strength and endurance capacity are only slightly correlated variables the changes in the correlations between the terminal threshold measurements (obtained at different rates of work load increase) and also between these and criteria mirroring strength and endurance capacity were studied. In this way the transition from anaerobic to aerobic work with increasing working time could be further analyzed.

Borg, G., Skinner, J.S., Bar-Or, O. Self-appraisal of physical performance capacity. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 32.

A method for self-appraisal of muscular strength and physical working capacity consisting of a simple 13-grade rating scale was applied in a study of the physical fitness of a group of 70 middle-aged men. The method functioned well as shown by similarities in means and standard deviations between ratings and laboratory measurements of the "same" variables. Significant correlations of the size .30 - .40 were obtained between self-ratings of fitness and measured fitness. The highest correlation, r = .52, was obtained between ratings of endurance fitness and preferred work load (for a moderate training session) for work on the tread-mill. The method is applicable in evaluating

other personality characteristics of importance for the understanding of people and their adaptation to the demands of work, leisure time activities etc. By comparing the subjective ratings with "objective" test results, quantitative measurements of an individual's "reality conception" can be obtained.

Bratfisch, O. Experienced intellectual activity and perceived difficulty of intelligence tests. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 30.

A battery of 10 intelligence tests was administered to 22 subjects under standard conditions. After the testing session the degree of perceived similarity between 5 tests of the battery was to be estimated with regard to (a) the kind of intellectual activity required by the tests and (b) difficulty. Estimated qualitative similarity (according to (a) above) was found to be a simple function of intertest correlation as determined from another group of 128 subjects. A correlation of 0.48 was found between estimates of qualitative similarity and similarity with regard to perceived difficulty and a correlation of 0.40 between the latter similarity variable and intertest correlation. When removing the effects of similarity with regard to perceived difficulty on the correlation between intertest correlation and estimated qualitative similarity ($r = 0.79$), a partial coefficient of correlation of 0.74 was yielded, indicating that perceived difficulty accounts for only 12 percent of the association of 0.79 present.

Bratfisch, O., Borg, G., and Dornič, S. Perceived item-difficulty in three tests of intellectual performance capacity. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 29.

Three tests of intellectual performance capacity referring to factors V, S, and R according to Thurstone's system of primary mental abilities were administered to a total number of 34 subjects. Immediately after finishing an individual item subjects were asked to estimate the perceived difficulty of that item. The ratings were to be given on a symmetric scale with 9 categories with verbal expression labels. A high correlation between tha rank order of items according to estimated difficulty and the real item sequence was obtained in all three tests used ($r \geq 0.92$). A linear relationship was found between estimated difficulty and standard scores corresponding to solution frequencies. A close correspondence was noticed between the widths and the levels of the ranges of the estimates on the one hand and the corresponding widths and levels of the standard score ranges on the other hand. Subjects who could solve an item correctly tended to estimate

the difficulty of that item as lower than subjects who could not.

Bratfisch, O., Dornič, S., and Borg, G. Perceived difficulty of items in a test of reasoning ability. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 28.

Sixty subjects participated in an experiment invòlving estimation of difficulty of items in a test of reasoning ability. The estimates were to be given both according to conventional conditions of magnitude estimations with a preassigned comparison standard and according to a modified procedure of magnitude estimation where the comparison standard was chosen individually by the subjects themselves. The test itself was administered to the subjects under standard conditions prior to the estimation procedures. When comparing the two methods of estimation used a high correlation between estimates and a close correspondence of the modified method of magnitude estimation to the methods of ratio estimation and similarity estimation was noticed. A high correlation ($r = 0.90$) between the rank order of items according to perceived difficulty and the item sequence in the test was found. Furthermore, estimated difficulty could tentatively be described as a positively accelerated function of standard scores corresponding to solution frequencies. The relative increase of perceived difficulty was more pronounced for subjects with a high performance score on the test than for subjects with a poor performance score. - Probable causes of the results obtained as well as possible secondary factors affecting the estimates of perceived difficulty are discussed.

Dornič, S. Immediate recall in a stress situation. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 34.

Twenty-five Ss were instructed to attend and respond to several sources of stimuli, the information load of the task being near the Sś maximum capacity. At the same time, auditory messages of digits were presented for immediate recall. The results showed the recall of item-information alone to be significantly lower than in a control condition (without stress), almost no difference being found in the recall of order-information. The results have confirmed previous findings from experiments on alcohol, noise and reduced attention, and are interpreted in terms of two coding levels in immediate memory.

Persaud, G. The performance of two samples of primary school children on two culture free and two culture bound intelligence tests. Reports from the Institute of Applied Psychology, the University of Stockholm, 1972, No. 26.

Two samples of primary school children (N = 32), denoted P and K respectively, served as subjects in an experiment in which two culture free and two culture bound intelligence tests were used. The samples differed only on the variables surroundings, socioeconomic status, and educational levels of the parents; the P sample represented the better of the two using the above variables as criteria. In three out of the four intelligence tests, statistically significant inter-sample mean differences were found in favour of the P sample. Differences between inter-test correlation coefficients in each sample varied with the statistical parameters used.

REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY
THE UNIVERSITY OF STOCKHOLM

ANNUAL REPORT

IV

1973

ANNUAL REPORT 1973

This report presents abstracts of papers reporting the research work of the Institute of Applied Psychology of the University of Stockholm. The first part of the report includes abstracts of works published in international journals and books. In the second abstracts of papers are presented which appeared in the series "Reports from the Institute of Applied Psychology".

The research work reported here was mainly supported by grants from the Swedish Council for Social Science Research and the Tercentenary Fund of the Bank of Sweden.

This report presents only abstracts of articles published in English or other international languages.

PUBLICATIONS IN INTERNATIONAL JOURNALS AND BOOKS

Borg, G. Perceived exertion: A note on "history" and methods. Medicine and Science in Sports, 1973, Vol. 5, 90-93.- Early studies of subjective force estimates for short-time work on a bicycle ergometer are reviewed. Results showed that perceived pedal resistance followed a positively accelerating function with an exponent of 1.6. A model for inter-individual comparisons using subjective range as a frame of reference is explained. Results of two experiments comparing four different rating methods are reported. Two methods involved the original Borg Scale and a variation, one graded from 1 to 21 and the other from 6 to 20. The third method utilized a line scale while the fourth scale was graded from 1 to 9 with 2 anchored by the expression "Not At All Stressful" and 8 with "Very, Very Stressful". These two experiments show that good correlations between heart rates and ratings are obtained independently of which scale is used. Since the Borg (6 to 20) Scale is the one most often used and gives values that grow fairly linear with work load and heart rate it is proposed that this scale be used in most cases.

Borg, G., Edgren, B., & Marklund, G. Two flexible work tests with feedback systems guiding the test courses. Proceedings, 17th International Congress of Applied Psychology, (R. Piret, Ed), Bruxelles, 1972, pp 393-398.- Two flexible work tests on bicycle ergometer are described. The first so-called CSET, the Cycling Strength and Endurance Test, is a pure performance test and takes into consideration the advantage of an interindividually fairly constant testing time. The test consists of a series of intermittently determined terminal thresholds (usually 10). At each determination the work load is continuously increased from an initially rather low level until the individual is unable to go on pedalling at the stipulated rate. Each determination lasts for about 45 sec and is followed by a short pause, usually 15 sec. The terminal thresholds form a curve which is analysed with respect to level, regression and residual variation, and gives information about the individual's dynamic muscular strength, endurance capacity, and motivation for physical work. The test has a very high reliability and a high correlation, not only with other tests but also with various field criteria of working capacity.

The second test described is the IAT, i.e. the Individually Adapted work Test. The test is constructed with stepwise increased work loads and a built-in feedback system for guiding the work load changes in accordance with the subject's heart rate as well as with his ratings of perceived exertion.

The purpose of the test is to obtain a behavioural measurement of physical working capacity in the form of the highest work load level on which a subject is able to work for 4 min (W max4min). The test is designed to have all subjects work for the same duration on a series of subjectively equal work loads instead of physically equal work loads. For practical and administrative reasons the testing time is kept short - about 10 min - and the initial work load fairly high. To meet these requirements the test is divided into two main parts (an initial and a final work period). The initial work period of 6 min is subdivided into three steering phases of 2 min each. Heart rate and ratings of perceived exertion, registered at the end of each steering phase, are used to determine the work load for the next one. The steering conditions cause the work load to be successively increased from phase to phase so that after the first 6 min the subject is supposed to have reached the highest work load on which he is able to continue for another 4 min.

Noble, B., & Borg, G. Perceived exertion during walking and running. Proceedings, 17th International Congress of Applied Psychology, (R. Piret, Ed), Bruxelles, 1972, pp 387-392.- Expenditure of energy during human locomotion is dependent upon a highly complex psychophysiological feedback system. The psychological and physiological components of this system most likely in concert, each acting to facilitate or inhibit the other, and therefore, the locomotor act. For instance, when a person engages in physical training programs, decisions to alter walking or running velocities involve psychological factors since perceptions of the exertion play an important role and physiological factors since mechanical and metabolic alterations are required. - The present authors conclude that a more complete explanation of human locomotion can be achieved by utilizing measurments of perceived exertion as a complement to standard physiological measurments.

An experiment is reported, in which the variation of perceived exertion is compared to that of oxygen uptake and heart rate during walking and running on the tread-mill. The results show that the two curves describing the intensity variation for walking and running, respectively, intersect at point 8.18 km x $hour^{-1}$ for oxygen uptake and 7.92 km x $hour^{-1}$ for heart rate. However, no intersection point for perceived exertion was found, i. e. running was always perceived to be significantly less exertive than walking at the same speed. The fact that no perceived exertion intersection point was observed in the velocity range utilized in this study (6.4 km x $hour^{-1}$ to 8.9 km x $hour^{-1}$) does not preclude the possibility that such a phenomenon may occur at a lower velocity. Walking at a speed of about 6 km x $hour^{-1}$ thus seems to elicit about the same degree of perceived exertion as running, in spite of the fact that the heart rate when running is about 20 beats x min higher than during walking. The practical significance of this results lies in its application to the prescription of exercise, e.g. for cardiac patients. Although walking at 6 1/2 km x $hour^{-1}$ may feel less comfortable than running at the same velocity, chances are that running at this velocity may put more burden upon the cardiovascular system.

PAPERS PUBLISHED IN THE REPORTS FROM THE INSTITUTE OF APPLIED PSYCHOLOGY, THE UNIVERSITY OF STOCKHOLM

Borg, G. A note on a category scale with "ratio properties" for estimating perceived exertion. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 36. - Some problems concerning category and ratio scales for estimating the degree of perceived exertion are discussed. A category scale with numbers from 0 to 20 is presented where 0 denotes no intensity at all and 20 a maximal intensity. Other verbal expressions such as "Very light" and "Somewhat hard" are included in the scale at positions corresponding to their subjective "ratio intensities". The purpose of this is to get the new category scale to function as a ratio scale. An experiment is reported which supports the possibility of constructing a category scale with ratio properties.

Borg, G. Perceived exertion during walking: A psychophysical function with two additional constants. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 39. - A psychophysical study was performed concerning perceived exertion when walking on a tread-mill. Ten subjects estimated the degree of perceived exertion according to the method of magnitude estimation. The subjects had to walk on a level surface (zero grade) during 4 minutes at six different speeds varying from 1.5 to 9 km x hour^{-1} (about 1 - 6 miles x hour^{-1}). The following power function was obtained:

$$R = 1 + 0.0125(S - 1.5)^3,$$

where R is the subjective intensity of perceived exertion when walking, the number one denotes the value of the basic perceptual noise level, which is equal to the R-value arbitrarily set to one at S = 1.5 km x hour^{-1}, 0.0125 is the measure constant, S is the physical speed in km x hour^{-1}, 1.5 shows the starting point of the curve and 3 is the exponent. The experiment has thus shown the need to include two additional constants in the power function, both a basic perceptual noise level and a low stimulus intensity, showing the starting point of the psychophysical function. This is the first empirical study in which the need for these two constants has been shown, in accordance with the general expression of the power function previously proposed by Borg (1961, 1962). The power function presented above may also be expressed in the following way:

$$R = 1 + 0.066(S - 1)^3,$$

where the physical speed is expressed in miles x hour^{-1} instead of km x hour^{-1}.

Borg, G., Edgren, B., & Marklund, G. The reliability and stability of the indicators in a simple walk test. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 35. - A simple walk test based on the subject's perception of his own walking speed and speed constancy has been studied for reliability and stability. Four different intructions for walking speed in two pairs were given on two separate days. The subjects walked the same track twice and in accordance with one pair of instructions for walking speed. For the first walk the induced speed - i. e. the induced work intensity - was lower than for the second. During each walk the subjects tried to keep the speed constant. Walking speed, heart rate and ratings of perceived exertion (according to the RPE-scale) were measured/obtained during and after each walk. The results showed that the subjects, 14 military conscripts, could clearly discriminate between different instructions for walking speed and could throughout each walk keep the speed with good constancy. Steady-state conditions were reached in heart rate and the course of the ratings of perceived exertion as expected showed a slight increase over time, which is in accordance with earlier findings. A retest after one month gave an even better individual constancy in walking speed.

Dornic, S. Phonological coding and order information. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 44. - Retention of order and item information was studied in two experiments in which subjects were to attend to a continuous perceptual-motor task, at the same time being presented with messages for immediate recall. In Experiment 1, visual tracking was used as a task to be attended to, the memory tasks being presented auditorily. In Experiment 2, subjects were instructed to attend to an "auditory tracking" task, the memory task being presented visually. In both experiments, the recall was inferior to a control condition where the subjects attended to the memory task itself. In Experiment 1, however, the overall decrease in recall was mainly due to a poorer retention of "item information only" i. e. to a poorer retention of messages with a wrong order of items, while in Experiment 2, the overall decline in recall was mainly due to a poorer retention of order information. It is argued that unless recall of p o s i t i o n s of the individual items in a message is involved, which requires "breaking up" of the phonologically coded chain traces, retention of order information might be thought of as a reduction rather than increase in the information stored. - Possible implications of the results in some work situations are pointed out.

Dornic, S., Borg, G., & Ohlsson, M. Physical effort and short-term memory. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 40. - A simple short-term memory paradigm, involving both forward and backward recall, was used to study the effect of arousal induced by light physical effort. Arousal appeared to improve recall by increasing the proportion of correct responses and/or by decreasing the processing time. In addition, the primacy/recency ratio was lower under physical effort, thus indicating

a more active information processing in the state of arousal.

Dornic, S., Bratfisch, O., & Larsson, T. Perceived difficulty in verbal learning. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 41. - Twelve learning tasks were constructed consisting of 20 words each. The tasks differed in meaningfulness and in the number and closeness of associations. The tasks were presented auditorily, at a rate of one word/1.3 sec. Each task was repeated seven times. After each presentation, the Ss had to recall the words in the order of presentation. Following each recall, the Ss were asked to give their estimates of perceived difficulty using a magnitude estimation method with perceived difficulty of the first trial serving as the standard. The results showed perceived difficulty to be primarily related to performance as measured by the number of correctly recalled words ($r = -0.98$), secondarily to the time per word in recall i. e. to the rate of the recall process ($r = 0.85$). Inadequacy of a global concept of perceived difficulty is pointed out and it is argued that perceived difficulty may be a m e d i a t e d experience, affected by a number of factors. In tasks such as the present one, not requiring any pronounced effort and enabling S to perceive his output on a quantifiable continuum, perceived difficulty appears to be mediated by perceived performance.

Dornic, S., Deneberg, G-B., & Hägglund, M. Visual search in dominant and nondominant languages. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 37. - Two experiments were carried out on the influence of short-term memory load on visual search. Forty-eight Swedish subjects with a fluent knowledge of English participated in the experiments. The stimulus field consisted of 49 numbers consisting of two digits or two words. In Experiment 1 the numbers were in the form of digits (e. g. 24), in Experiment 2 in the form of either Swedish or English words (e. g. "twenty-four"). The subjects looked for one, two or three targets at the same time. While searching, they were to keep in mind the target names either in their dominant or in their nondominant language. The results showed that the search time grew, in all conditions, as positively accelerated function of the number of targets looked for at the same time, this trend being significantly more pronounced when search was made in the nondominant language. On an average, the search time for symbols (Experiment 1) was shorter than that for words (Experiment 2), but the increase in search time under memory load was relatively greater in Experiment 1.

Dornic, S., Hagdahl, R., & Hanson, G. Visual search and short-term memory in the deaf. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 38. - A group of deaf Ss and two groups of hearing Ss participated in an experiment on visual search with different loads on short-term memory. The S´s task was to learn one, two or three

letter-digit combinations (Condition 1, 2 and 3 respectively) and then to look for them on a matrix consisting of 49 such combinations (Fig. 1). In Conditions 2 and 3, only one of the combinations (targets) really appeared on the matrix. Before starting the search task, a correct written recall of the target set was required. The results showed no difference between the deaf and the hearing Ss in Condition 1, either in learning time or in search time. In Conditions 2 and 3, the deaf Ss' learning time increased considerably as compared with the hearing Ss' learning time, but there was no significant difference between the groups as to the search time. There was a clear tendency in the deaf to learn the target set according to categories (letters, digits) rather than according to the order. In contrast to the hearing Ss, the deaf tended to have shorter search times for the homophone target sets than for non-homophone ones. The results are discussed as being due to the deaf's predominant coding strategies (visual, dactylic and category coding) which, in comparison with phonological coding used by the hearing Ss, make storing and rehearsal of order-information more difficult. On the other hand, the matching process involved in search may be easier for the deaf who, in contrast to the hearing, may match the memory trace more directly against the visual input. Phonological coding has again been shown to be a disadvantage in tasks consisting of homophone units.

Dornic, S., Sarnecki, M., & Svensson, J. Perceived difficulty, learning time and subjective certainty in a perceptual task. Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 43. - A series of 5-alternative forced-choice perceptual tasks were constructed, the S being instructed to (1) identify the correct item, (2) indicate his degree of confidence in his choice, and (3) estimate the degree of (perceived) difficulty of the task. The main experimental variable was learning time i. e. the time during which the Ss inspected the criterion items before they tried to identify them among the comparison items. The data showed a close relationship between perceived difficulty, confidence, and performance, respectively, the correlation coefficients being somewhat higher for high-performance subjects than for low-performance ones. The results are in line with earlier findings indicating that perceived difficulty may be considered a m e d i a t e d experience affected by a number of factors. In learning tasks such as the present one, the subject receives no information feedback and is thus unable to perceive his output on a clear-cut quantifiable continuum. Under these circumstances, subjective certainty appears to play an important role in the experience of difficulty. "Stress of time" seemed to be another essential factor contributing to the increase in perceived difficulty.

Hallsten, L., & Borg, G. Exponents and skews of equal-settings: An empirical study of the "Dispersion method". Reports from the Institute of Applied Psychology, the University of Stockholm, 1973, No. 42. - Departing from the "Dispersion method" it is possible to derive exponents in the psychophysical

function from the skewness of distributions of equal-settings. Ten subjects gave 40 equal-settings to each of three standard stimuli from the continua line length, loudness and circle area. Most distributions were positively skewed, but were less so for the higher stimulus values. The derived exponents deviated clearly from the usually obtained ones for line length and circle area, being mostly too low or too high (<0.10 or <2.0). For loudness the attempt was somewhat more successful but the standard deviations of the exponents were considerable. It was argued that it is of importance to take care of possible artifacts, such as the central tendency effect, since minor influences on the distributions can produce pronounced deviations in the exponents. To elaborate a more complex model seems also desireable.

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EXERCISE PERFORMANCE AND PERCEIVED EXERTION IN PATIENTS WITH CORONARY INSUFFICIENCY, ARTERIAL HYPERTENSION AND VASOREGULATORY ASTHENIA[1]

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Abstract. A standardized work test has been performed by healthy subjects, patients with coronary heart disease, patients with arterial hypertension, and with the vasoregulatory asthenia syndrome. Heart frequency and rating of perceived exertion according to a rating method were assessed at various work loads. Different measures of physical working capacity were estimated.

Patients with vasoregulatory asthenia—and patients with arterial hypertension, although less markedly—rated the exertion to be less in relation to heart frequency than healthy controls, particularly at low rating levels. On the contrary, patients with coronary heart disease rated the exertion to be higher, particularly at high ratings, in relation to heart frequency.

In all patient groups studied, there was a smaller mean increase in heart rate in relation to a given increase in rating of exertion, i.e. for a given increase in heart rate there was a greater increase in rating of exertion than in healthy controls.

Submaximal measures of physical working capacity were based on heart rate and rating of perceived exertion. The ratio between measurements of physical working capacity based on heart rate and those based on rating of perceived exertion was low in the VA group and high in patients with coronary insufficiency when compared with controls of equal age. Patients with a low "maximal" performance during the test also had a low submaximal physical working capacity estimated from heart frequency as well as from rating of perceived exertion.

The difference found between the various patient groups, especially that between patients with coronary heart disease and patients with the vasoregulatory asthenia syndrome is of differential diagnostic value.

In healthy subjects there is a fairly close relationship between heart rate during exercise and the subjective perception of exertion according to a rating method (3). This relationship changes with the age of the subject (5). Having used rating of perceived exertion for several years in routine tests for the determination of the physical working capacity of patients we got the impression that in some groups of patients there is a deviation from normal relationships between heart rate and rating of exertion. Thus Borg and Linderholm (4), cf. also Borg (3), reported that patients with arterial hypertension and coronary insufficiency rated the exertion high in relation to heart rate as compared with controls.

In the present investigation different groups of patients were compared with healthy subjects of comparable age in order to further elucidate these differences. At the same time different methods of estimating the physical working capacity have been compared.

MATERIAL

Groups of patients with the vasoregulatory asthenia syndrome (8), coronary heart disease and arterial hypertension were selected from about 7000 patients who were examined during a three-year period for diagnostic purposes with ECG at rest, during and after exercise at the Department of Clinical Physiology, University Hospital, Umeå. Consecutively examined patients who fulfilled the criteria to be described below were included in the study. All patients with digitalis medication, signs of valvular heart disease, and with ECG changes or history typical of previous heart infarction were excluded. Groups of healthy age-compatible control subjects were included in the study for comparison. Some general characteristics of the groups are given in Table I. The patient groups are to a great extent identical with those included in a study on the effects of hyperventilation on ECG (6).

[1] A report of this paper was given at the Umeå Medical Association in 1967.

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Table I. *Some characteristics of the male and female groups of patients with vasoregulatory asthenia (VA), coronary heart disease (C), hypertension (H), groups of healthy subjects (N) and groups of healthy male lumber workers (LN), lumber workers with coronary insufficiency (LC) and those complaining of pains in knee joints or in the back during exercise (LP)*

For further details see text under Material

Group	Sex	*n*	Age, y. Mean	Age, y. Range	Height, cm Mean	Weight, kg Mean
VA	♂	11	28	20–39	174	67
	♀	11	31	21–38	164	61
C_I	♂	24	59	50–67	170	72
	♀	8	57	51–66	159	67
C_{II}	♂	8	54	50–64	174	77
	♀	2	52	51–53	165	71
H_I	♂	13	58	50–63	173	77
	♀	22	57	51–69	160	68
H_{II}	♂	14	58	51–65	173	83
	♀	16	54	50–61	162	69
N_I	♂	71	28	20–39	177	71
	♀	20	22	20–28	161	55
N_{II}	♂	25	60	51–69	174	78
	♀	8	62	52–67	159	65
N_{III}	♂	30	19	18–20	176	69
	♀	14	19	18–20	166	59
N_{IV}	♂	27	23	20–24	177	68
	♀	20	21	20–24	163	57
LN	♂	35	50	45–59	173	70
LC	♂	7	51	45–60	168	75
LP	♂	10	50	45–55	173	68

Group VA included patients with the pathophysiological *vasoregulatory asthenia* syndrome (8). These patients were usually comparatively young and only those between 20–39 years of age were selected. They were characterized by a history suggesting such diagnoses as myocarditis, angina pectoris, Da Costa's (effort) syndrome, heart neurosis, etc. They all had a low physical working capacity (PWC_{170}) in relation to the total amount of hemoglobin (THb) and blood volume, a high heart rate at rest (mean 99 beats/min in males and 105 beats/min in females) and at an orthostatic test (mean 124 beats/min in males and 129 in females). Sympathicotonic ECG changes were present at rest, during an orthostatic test, or during exercise. For those in whom the heart volume was determined (i.e. the majority of these patients) the PWC_{170} was low also in relation to heart volume while the relationship between heart volume and THb were normal. In several of them the physical working capacity increased towards normal values in relation to THb or heart volume after ganglionic blocking with chlorisonamine (about 0.1 mg/kg) and in some after physical training (1). In some of them a heart catheter study revealed a hyperkinetic circulation. They all had normal blood pressure and no signs of hyperthyreosis or anemia.

Patients with *coronary heart disease* and *arterial hypertension* between 50–69 years of age were divided into groups with low and ordinary working capacity as follows:

(I) The groups with low physical working capacity included male patients who worked less than 4 min at a final work load of 900 kpm/min on the bicycle ergometer and female patients who worked less than 4 min at a final work load of 600 kpm/min (cf. Methods). Often they stopped work because of symptoms of pain, exhaustion etc. in spite of a low heart rate.

(II) The groups defined as having an ordinary physical working capacity included patients who were able to work at least 4 min on a work load of 900 kpm/min in the case of males and 600 kpm/min in the case of females. The following subgroups were obtained:

Group C_I included patients with coronary heart disease with a low physical working capacity and a typical history of angina pectoris. As a rule they were sent for examination with this diagnosis. ECG during and after exercise showed changes typical of coronary insufficiency (cf. references 12, 14) and during exercise chest pains were usually felt. Their arterial blood pressure was below the low limit for the patients with arterial hypertension.

Group C_{II} included patients with coronary heart disease who had an ordinary working capacity (vide supra) and otherwise fulfilled the same criteria as Group C_I.

Group H_I included patients with arterial hypertension and a low physical working capacity. The diagnosis arterial hypertension had been established for several years. At the present examination the arterial blood pressure at rest was 160/100 mm Hg (systolic/diastolic) or more and during exercise 240 mm Hg (systolic) or more. During exercise the ECG changes were not typical of coronary insufficiency.

Group H_{II} included patients with arterial hypertension who fulfilled the same criteria as group H_I but had an ordinary physical working capacity.

Control groups included subjectively healthy volunteers who had in most cases a normal ECG at rest, during and after exercise. In a few cases of the older age group slight unspecific ST-depressions were present. However, the ECG during exercise did not suggest coronary insufficiency. They performed a work test without complaints. The males were to a large extent included in the groups described by Borg and Linderholm (5). All subjects with blood pressure in the hypertensive range were excluded.

Group N_I, "young controls", were particularly used for comparison with the VA-group and therefore selected in the age range of 20–39 years. The males were mainly university students and teachers and the females nurses and laboratory assistents.

Group N_{II}, "old controls", were particularly used for comparison with the patient groups with coronary heart disease and arterial hypertension in the 50–69 year range. These subjects had various occupations and were considered healthy at a general medical examination.

Group N_{III} and *Group* N_{IV} included males and females of equal age. The females of group N_{III} only worked on two loads (200 and 400 kpm/min) and only a few rated the work as "very laborious" (R_{17}). Together with Group N_{II} these groups, covering a wide age range, were used to compare males and females of equal age.

Some groups of *lumber workers* were also studied. They included all subjects from a group of 80 lumber workers—

Table II. *Reproducibility of various measures of physical working capacity estimated from double determinations made with an interval of two to four weeks in patients, nine males and ten females, examined for functional and organic heart diseases of slight or moderate degree and in controls, twelve males and five females*

		PWC_{130}	PWC_{170}	PWC_{R13}	PWC_{R17}	PWC_P	PWC_{max}
Patients	$\bar{x}_{1+2}$	435	745	531	780	638	766
Nine males	S_{x1}	190	278	198	249	263	281
Ten females	S_e	59.4	40.2	95.4	66.0	56.6	71.2
	v	13.3	5.3	18.1	8.3	8.9	9.3
	r	0.93	0.98	0.80	0.94	0.96	0.93
Controls	$\bar{x}_{1+2}$	710	1175	887	1272	1136	1259
Twelve males	S_{x1}	226	332	361	447	322	402
Five females	S_e	82.8	61.4	108.9	66.5	69.2	55.2
	v	11.7	5.2	12.3	5.2	6.1	4.4
	r	0.88	0.97	0.91	0.98	0.96	0.98

$\bar{x}_{1+2}$ = mean value from the two work tests. S_{x1} = standard deviation of first examination. S_e = standard error of a single determination, estimated from double determinations. v = coefficient of variation, %, of a single determination. r = correlation coefficient, correlation between double determinations.

to some extent described earlier (3, 5)—who fulfilled the criteria defined below and were within the age ranges given in Table I. All of them were examined with ECG at rest, during and after exercise. They were subjectively healthy.

Group LC had ECG changes typical of coronary insufficiency appearing during heavy work. All of them worked 900 kpm/min or more for 6 min and had arterial blood pressures below those of the groups with arterial hypertension (H_I and H_{II}).

Group LP included lumber workers who complained of pains in knee joints and in the back during the exercise test but had normal ECG and arterial blood pressure.

Group LN had normal ECG or only minor ECG changes at rest, during and after exercise and arterial blood pressures below the hypertensive range. This group was almost identical with the group of lumber workers, age 45–54, described by Borg and Linderholm (5).

METHODS

All subjects performed a work test on a bicycle ergometer according to Sjöstrand (13) and Wahlund (16). The work started with a work load of 200 kpm/min for females and a few males with a low working capacity and 300 kpm/min for most males. The work load increased stepwise from the initial load. The work on each load lasted for 6 min. Unless otherwise stated, the suject worked until unable to continue, or until the subject reached a high heart rate and rated the perceived exertion as high ($R_{17} - R_{19}$), or the test had to be interrupted for other reasons such as ECG changes, anginal pains, or a rise of the systolic arterial blood pressure above 300 mm Hg.

ECG was recorded during exercise (cf. ref. 6). Heart rates were taken after 2, 4 and 6 min at each work load by measuring on the ECG curve. The maximal heart rate observed during the work test was recorded, usually just before the work was interrupted.

After 5 min work on each load (on the highest load before the end of the work) the degree of perceived exertion was rated using a rating scale (3). The rating scale consisted of 21 grades with every second figure from three to nineteen anchored by verbal expression as "very light", "rather laborious", etc. It was found impossible to use a more elaborate psychophysical scaling method as it was dificult for the ordinary patient to understand the instruction or to use numbers according to mathematical rules that most psychophysical ratio methods demand.

The rating scale has been used by Borg and Linderholm (5) in an investigation concerning the changes in the relationships between subjective exertion and heart frequency during physical work in various age groups.

Evaluation of physical working capacity

PWC_{130} and *PWC_{170}*. Submaximal measures of physical working capacity were determined from the heart rate at known work intensities as follows:

The work loads on the bicycle ergometer (kpm/min) corresponding to two heart rate reference levels of 130 and 170 beats/min were estimated by linear inter- or extrapolation in a "heart rate-work load diagram" and were used as measure of physical working capacity (PWC_{130} and PWC_{170}) of an individual (13, 16). Extrapolation was only made if the heart rate after at least 4 min work on the highest load was within 20 beats per min of the heart reference level.

PWC_{R13} and *PWC_{R17}*. In a similar way measures of physical working capacity were estimated from the rating of perceived exertion by linear interpolation or extrapolation in the "rating value-work load diagram" making use of the fairly linear relationship between rating value and work load (between $R_9 - R_{17}$). The rating values 13 and 17 were used as reference levels giving the measures of physical working capacity PWC_{R13} and PWC_{R17}. Extrapolation was only made if the rating value of perceived exertion obtained after at least 4 min work on the highest load was within 2 units of the rating reference level. The rating values 17 or 19 were occasionally given after only a few minutes work on the highest load shortly before

Table III. *Mean heart rate at various rating values ($\bar{X}$) and mean differences ($\bar{D}$) between groups of males and females of equal age ($\bar{D}$)*

Group (age range)	Sex		Rating value 9	13	17
N_{III} (18–20)	♂	n	16	29	
		$\bar{X}$	137	159	
		S_x	18	20	
	♀	n	14	12	
		$\bar{X}$	134	162	
		S_x	19	14	
		$\bar{D}$ (♂–♀)	3	−3	
N_{IV} (20–24)	♂	n	24	27	19
		$\bar{X}$	121	147	172
		S_x	12	17	10
	♀	n	18	20	13
		$\bar{X}$	132	154	178
		S_x	13	15	8
		$\bar{D}$ (♂–♀)	−11*	−7	−6
N_{II} (50–59)	♂	n	15	25	
		$\bar{X}$	102	126	
		S_x	16	17	
	♀	n	7	8	
		$\bar{X}$	107	134	
		S_x	19	17	
		$\bar{D}$ (♂–♀)	−5	−8	

In this and the following tables the probability (P) that differences are caused by random factors is denoted as follows: *$=0.05>P>0.01$. **$=0.01>P>0.001$. ***$=P<0.001$. Differences without asterisks$=P>0.05$. Other symbols as in Tables I and II.

the work was interrupted. Such rating values have not been used in this analysis.

PWC_P was estimated as described by Borg and Linderholm (5) by using a heart rate reference level (HRL) variable with age between 20 and 80 years of age according to the equation $HRL_{50\ per\ cent} = 170 - [2(A-20)/3]$, where A is the age in years and $HRL_{50\ per\ cent}$ corresponds to about 80% of the maximal possible increase in heart rate from the resting level. The submaximal working capacity at this heart frequency level was PWC_P.

PWC_{max}. The maximal work intensity performed, PWC_{max}, was taken as the heaviest load at which the subject actually worked for 6 min. If the subject was able to work on a higher load for less than 6 min a fraction of the stepwise increase in work load, corresponding to a fraction of the 6 min period in which the subject was able to continue work on this higher load, was added (cf. ref. 14). No attempt was made to get objective evidence of maximal performance in terms of high blood lactate concentrations etc., and PWC_{max} is not regarded as being equivalent to measure of maximal performance where such methods were employed (cf. also Discussion).

Methodological error of the PWC measures

An estimate of the error of the PWC measures can be obtained from *intra-test correlations* of heart rates and rating values of perceived exertion.

By using heart rates from the work loads 300 and 900 kpm/min to obtain one estimate of PWC_{130} and the heart rates from 600 and 1200 kpm/min to obtain another estimate of PWC_{130}, from work tests which included these four work loads, the correlation between two PWC_{130} values obtined from "different parts" of the same work tests was calculated in a group of 54 healthy subjects. The correlation coefficient was found to be 0.84 and the reliability coefficent was estimated at 0.91 (after correction according to Spearman-Brown's formula) (7).

In a similar way two PWC_{R13} values were estimated from rating values of perceived exertion at work loads 300 and 900 kpm/min and from ratings at 600 and 1200 kpm/min. The correlation between the two PWC_{R13} values was calculated for the same group of 54 subjects. The correlation coefficient was 0.85 and the reliability coefficient was estimated at 0.92 (after correction according to Spearman-Brown's formula).

The intra-test correlations obtained for the two different kinds of measure of PWC indicate a low methodological error. This error tends to decrease at a high reference level of heart frequency or rating (vide infra) and therefore the intra-test correlation for PWC_{170} and for PWC_{R17} should be at least 0.90. PWC_{170} or PWC_{R17} was about 1200 ± 200 (mean $\pm$ S.D.) kpm/min. Then the error of a single determination (s_e) of PWC according to the formula $s_e = s_x\sqrt{1-r}$ (where s_x is the S.D. in the group) should be $s_e = 200 \times 0.3 = 60$ kpm/min, i.e. about 5% of the mean value.

The error of the PWC measures can also be estimated from *repeated examinations* of the same individuals. Using this approach the overall error in the measures of PWC was estimated from double determinations made with an interval of 2–4 weeks. A comparatively long period between the tests was chosen in order to minimize the effect of memory on the rating of perceived exertion. Patients with various heart- and other diseases, but with comparatively well preserved physical working capacity, and healthy subjects were used for this study. The results appear in Table II. The measures based on observations made on a relatively high work load, PWC_{170} and PWC_{R17}, have a smaller error than those based on observations obtained at relatively low work loads, PWC_{130} and PWC_{R13}. The error of the determination of the PWC measures based on heart rate seems to be sligthly smaller in the patient group than those based on observations made on the rating of perceived exertion. The error of the PWC_{170} is larger than that found in normal subjects when double determinations were made with an interval of 1–2 days (10) but of the same magnitude as that reported by Bevegård et al. (2) when examining patients with heart disease with an interval between double determinations comparable to that used by us.

RESULTS

The relationship between heart rate and rating of perceived exertion in the groups of patients and healthy controls

Healthy male and female controls of three age groups, 18–20, 20–24 and 50–69 years of age,

Table IV. *Mean heart rate of control and patient groups and mean differences in heart rate between groups at rating values R_9 ("rather light"), R_{13} ("rather laborious") and R_{17} ("very laborious")*

Figures within brackets give the number of subjects. In case of differences the figures within brackets represent the number of subjects in the last group. Symbols as in Tabels I and III

Group	Rating value 9		13		17	
	Mean value heart rate of healthy control groups					
N_I	121	(84)	149	(90)	172	(49)
N_{II}	103	(20)	128	(32)	152	(13)
LN	101	(30)	129	(35)	157	(21)
	Mean difference in heart rate between groups					
N_I–VA	−24.4***	(10)	−16.1***	(20)	−7.1	(12)
N_{II}–C_I	−4.2	(20)	4.8	(26)	15.3*	(20)
N_{II}–C_{II}	−3.3	(7)	11.0	(10)	12.2	(9)
LN–LC	7.7	(6)	22.4*	(7)	21.0*	(5)
$(N_{II}+LN)-(C_I+C_{II}+LC)$	−2.8	(33)	9.4**	(43)	17.3***	(34)
N_{II}–H_I	−9.7*	(19)	−1.7	(30)	5.4	(24)
N_{II}–H_{II}	−12.1*	(23)	−0.7	(31)	1.1	(21)
LN–LP	−3.8	(10)	5.9	(9)	10.8	(6)
N_{II}–N_I	−18.1***	(84)	−20.4***	(90)	−20.1***	(49)
N_{II}–LN	2.3	(30)	−0.7	(35)	−4.3	(21)

were compared with regard to the heart rate at given rating values of perceived exertion (Table III). The females had on an average a sligthly higher heart rate at equal rating. The difference was not statistically significant except at low rating, R_9, in the group 20–24 years of age ($P < 0.05$). Owing to the small difference between men and women we treated them together when comparing the relationship between heart rate and rating of perceived exertion in the patient and control groups.

Figs. 1–3 show the relationship between heart frequency and perceived exertion in some different patient groups compared with control groups. The differences in heart rate at given rating values of perceived exertion between control and patient groups and their statistical significance are given in Table IV. Table V gives the slopes,

Table V. *Mean increase in heart rate for increase in rating value from 9 to 13, Δ (heart rate)$_{R9-13}$, and from 13 to 17, Δ (heart rate)$_{R13-17}$, and mean differences in these mean increases in heart rate between groups*

Figures within brackets give the number of subjects. In case of differences the figures within brackets represent the number of subjects in the last group. Symbols as in Tables I and III

Group	Δ (heart rate)$_{R9-13}$		Δ (heart rate)$_{R13-17}$	
	Mean increase in heart rate			
N_I	27.7	(83)	28.9	(49)
N_{II}	22.2	(19)	31.1	(13)
LN	32.3	(28)	32.3	(21)
	Mean difference			
N_I–VA	4.6	(9)	8.6**	(12)
N_{II}–C_I	5.5	(15)	14.7**	(16)
N_{II}–C_{II}	3.3	(7)	4.0	(9)
LN–LC	14.8*	(6)	−5.5	(5)
$(N_{II}+LN)-(C_I+C_{II}+LC)$	10.8***	(28)	8.6*	(30)
N_{II}–H_I	2.6	(19)	8.5*	(18)
N_{II}–H_{II}	1.7	(23)	6.9	(21)
LN–LP	14.1*	(9)	5.8	(6)
N_{II}–N_I	−5.5	(83)	2.2	(49)
N_{II}–LN	−10.1*	(28)	−1.2	(21)

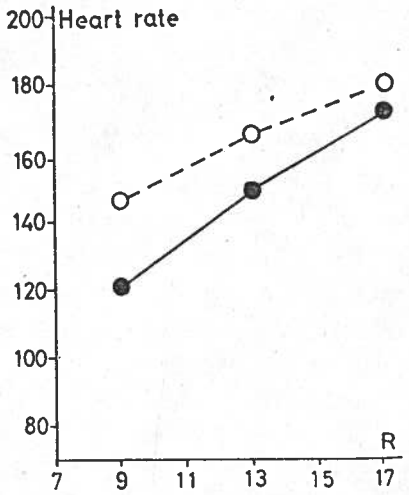

Fig. 1. The relationship between heart rate and perceived exertion (*R*) in a control group (N_I) ●—●, and a group of patients with vasoregulatory asthenia (VA) O--O, including males and females.

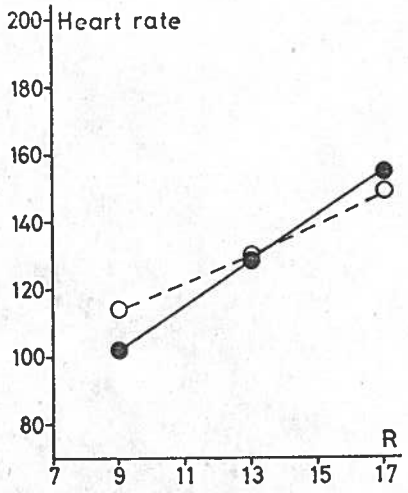

Fig. 3. The relationship between heart rate and perceived exertion (*R*) in a control group (N_{II} – LN) ●—●, and two groups of patients with arterial hypertension (H_I and H_{II}) O--O, including males and females.

i.e. the increase in heart rate for increase in the rating value from 9 to 13, $\Delta(\text{heart rate})_{R9-13}$, and from the rating 13 to 17, $\Delta(\text{heart rate})_{R13-17}$ in various groups, as well as differences in slopes between control and patient groups.

Vasoregulatory asthenia. Fig. 1 and Table IV demonstrate differences between the VA group and the control group at the rating values 9 and 13 but not at high rating values of perceived exertion (R_{17}). The slope, $\Delta(\text{heart rate})_{R13-17}$, of the VA groups was statistically significantly smaller than that of the controls (Table V). There were only slight and statistically insignificant differences in heart rate at given rating values and in slope between VA patients with a PWC_{max} less than the mean of the group and those with a PWC_{max} above the mean.

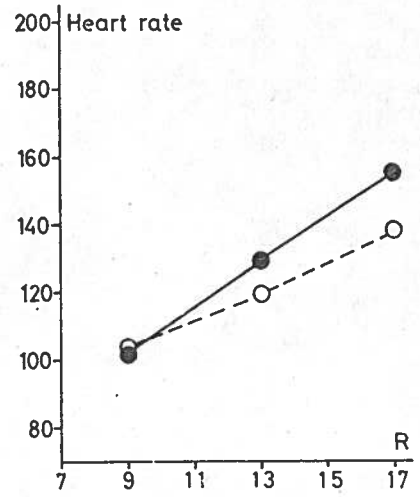

Fig. 2. The relationship between heart rate and perceived exertion (*R*) in a control group (N_{II} – LN) ●—●, and three groups of patients with coronary insuficiency (C_I, C_{II} and LC) O--O, including males and females.

The coronary insufficiency group with a low physical working capacity, C_I, differed statistically significantly in heart rate at the rating value 17 from the control group of comparable age (Table IV). No such differences were present at the rating values 9 and 13 or in the coronary insufficiency group with an ordinary physical working capacity, C_{II}. The slope, $\Delta(\text{heart rate})_{R13-17}$, of the group C_I (but not group C_{II}) was statistically significantly smaller than that of the controls (Table V).

In the group of lumber workers with coronary insufficiency, group LC, the heart rate at the rating values 13 and 17 as well as the slope, $\Delta(\text{heart rate})_{R9-13}$, was smaller than that of the control group of healthy lumber workers, group LN (Tables IV and V). In these respects the lumber workers with coronary insufficiency differ from the group of lumber workers with pains in knee joints and back, group LP, which did not differ

Table VI. *Mean values ($\bar{x}$) of maximal recorded heart rate and various measures of physical working capacity in the different patient groups and in groups of healthy controls*

Mean values ($\bar{x}$) and the number of subjects (n) from which the means were calculated. Symbols as in Tables I and II

		Max heart rate		PWC_{130}		PWC_{170}		PWC_{R13}		PWC_{R17}		PWC_P		PWC_{max}		PWC_{130}/PWC_{R13}		PWC_P/PWC_{R17}	
Group	Sex	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$	n	$\bar{x}$
VA	♂	11	188	11	247	11	573	10	485	8	789	11	521	11	745	10	0.59	8	0.69
	♀	11	182	10	88	11	358	11	328	10	501	11	292	11	467	10	0.32	10	0.60
C_I	♂	24	135	17	488	3	770	20	419	13	558	17	635	24	513	15	1.15	10	1.03
	♀	8	149	5	291	2	305	8	317	3	457	7	476	8	404	4	0.82	3	0.76
C_{II}	♂	8	145	8	773	3	995	8	597	8	909	8	971	8	906	8	1.41	8	1.09
	♀	2	167	2	470	2	655	2	385	2	555	2	545	2	617	2	1.31	2	1.05
H_I	♂	13	151	10	499	4	686	11	486	5	671	10	637	13	592	10	1.00	5	0.87
	♀	22	151	19	309	8	468	17	317	14	418	19	401	22	408	16	0.99	13	0.90
H_{II}	♂	14	151	14	686	7	1039	14	677	11	936	14	846	14	945	14	1.04	11	0.85
	♀	16	164	16	407	12	654	16	392	14	584	16	512	16	610	16	1.20	14	0.90
N_I	♂	71	179	71	720	71	1188	70	905	59	1266	71	1110	71	1291	70	0.81	59	0.90
	♀	20	184	20	388	20	670	20	564	18	759	20	648	20	760	20	0.70	18	0.86
N_{II}	♂	25	157	24	697	18	1088	25	647	21	984	24	847	25	951	24	1.12	21	0.89
	♀	8	155	8	488	2	760	8	527	4	715	8	569	8	634	8	1.00	4	0.80
LN	♂	35	162	35	878	23	1194	35	896	27	1210	34	1062	35	1110	35	1.03	26	0.89
LC	♂	7	147	7	900	1	1470	7	643	5	1020	7	1116	7	1021	7	1.66	5	1.18
LP	♂	10	146	9	767	2	1110	9	708	7	1071	7	877	10	915	9	1.15	5	0.84

statistically from the control group of lumber workers.

By adding N_{II} and LN to form a larger control group and comparing this group with a coronary insufficiency group obtained by adding C_I, C_{II} and LC, highly significant differences between the control group and the coronary insufficiency group were obtained in the relationship between heart rate and rating value (see Table IV, and Fig. 2).

The groups with *arterial hypertension* deviated from the controls in a similar way to the VA group but less markedly. A statistically significant difference in heart rate ($P < 0.05$) was obtained at the rating value 9 ("rather light" work) between group N_{II} and the groups H_I and H_{II} (Table IV). There was a slight difference in slope between group H_I and group N_{II} (Table V, cf. also Fig. 3).

Control groups. There were obvious differences between the young and old subjects as shown by control groups N_I and N_{II}. It should be noted that the difference between the VA group and group N_I in heart rate at a given rating value is not similar to that between group N_I and group N_{II}. This is also shown by the differences in slopes $\Delta(\text{heart rate})_{R9-13}$ and $\Delta(\text{heart rate})_{R13-17}$ between $(N_I - VA)$ and $(N_{II} - N_I)$, see Table V.

Physical working capacity estimated from heart rate, rating of perceived exertion, and work performed (PWC_{max})

Some results of the various methods of estimating physical working capacity in the patient and control groups are given in Table VI. With the restriction on extrapolation in the work load–heart rate or work load–rating value diagrams (see Methods) applied in the present investigation, all measures of PWC were not obtained in all subjects. Particularly among the patients with coronary insufficiency and arterial hypertension, PWC_{170} was obtained from a limited number of subjects due to the fact that the heart rate on the highest work load was often less than 150 beats/min. In some cases it was less than 110 beats/min and then PWC_{130} was not obtained. Several subjects did not rate the perceived exertion so high (R_{15}) after more than 4 min work on the highest load that PWC_{R17} could be estimated.

According to earlier described changes in the relation between heart rate and rating of perceived exertion with age (5) the PWC values calculated from the heart rate, as well as PWC_{max}, were

Table VII. *Mean differences between groups in the ratios PWC_{130}/PWC_{R13} and PWC_P/PWC_{R17}*

The groups include males and females and correspond to those given in Table VI

Group	PWC_{130}/PWC_{R13}	PWC_P/PWC_{R17}
N_I–VA	0.34***	0.25***
N_{II}–C_I	0.01	−0.10
N_{II}–C_{II}	−0.30*	−0.21*
LN–LC	−0.63***	−0.29*
$(N_{II}+LN)$–$(C_I+C_{II}+LC)$	−0.22**	−0.17**
N_{II}–H_I	0.09	−0.02
N_{II}–H_{II}	−0.03	−0.01
LN–LP	−0.12	0.06
N_{II}–N_I	0.30***	−0.02
N_{II}–LN	0.06	−0.02

relatively low in relation to those obtained from the rating of perceived exertion in the control group N_I (20–39 years of age) when compared with the control group N_{II} (50–69 years of age). Still lower PWC values estimated from the heart rate in relation to those obtained from the rating of perceived exertion and PWC_{max} were found in the VA group.

The patients of groups C_I and H_I, who had low maximal physical performance, PWC_{max}, also had low PWC_{130} and PWC_{R13} compared with the control group N_{II}. Patients of groups C_{II} and H_{II} had approximately similar mean PWC values to the controls. PWC_P compared fairly well with PWC_{R17} and PWC_{max} in all except the VA group, in which PWC_P was relatively low.

The ratios PWC_{130}/PWC_{R13} and PWC_P/PWC_{R17}

Out of several possible ratios between the measures of physical working capacity the ratios PWC_{130}/PWC_{R13} and PWC_P/PWC_{R17} were found to be particularly interesting. These ratios were found to be fairly equal in male and female groups (Table VI) and therefore, in a comparison of these ratios between groups, males and females were treated together (Table VII).

The ratio PWC_{130}/PWC_{R13} was higher in group N_{II} than in N_I, while the ratio PWC_P/PWC_{R17} seems to be quite independent of age (Tables VI and VII).

In the VA group the two ratios PWC_{130}/PWC_{R13} and PWC_P/PWC_{R17} were low, while they were high in the groups of coronary insufficiency when compared with age-compatible control groups. Patients with hypertension did not differ from healthy controls, nor from the group of lumber workers with pain in back and legs (Table VI and VII).

DISCUSSION

The results show that there is a difference between the controls and the patient groups. The VA patients have a high heart rate in relation to the rating of perceived exertion, particularly at the low work loads. They do not rate the exertion as high as do the controls at the same, comparatively low heart rates. The patients with arterial hypertension deviate from their controls in a similar way though less markedly, a result which deviates somewhat from that of the preliminary study (4). On the other hand the patients with coronary insufficiency, especially those with a low work tolerance, have a low heart rate in relation to their rating of exertion, particularly at high rating values.

All patient groups are similar in the respect that the mean value for their increase in heart rate in relation to increase in rating of subjective exertion is smaller than in the control groups. Stated in another way the patients' perceived exertion increases more rapidly with a given increase in heart rate than that of controls.

As a consequence of the deviation of some patient groups from normal relationships between heart rate and rating of perceived exertion during exercise the relationships between the different measures of PWC used in this study also deviate from those found in healthy controls of comparable age. In the VA group the measures of PWC based on heart rate, PWC_{130} and PWC_{170}, are thus comparatively low in relation to those based on rating of perceived exertion, PWC_{R13} and PWC_{R17}, while the opposite, though less markedly so, is true of patients with coronary insufficiency. Young and old control groups differ to some extent in a similar way to VA and coronary insufficiency patient groups.

Some ratios between the measures of physical working capacity, PWC_{130}/PWC_{R13} and PWC_P/PWC_{R17}, are useful for demonstrating these differences. There do not seem to be marked sex differences in these ratios and the ratio PWC_P/PWC_{R17} seems to be independent of age. The ratio PWC_{130}/PWC_{R13} can be used in the case

of patients who do not reach high heart rates during exercise. Both these ratios are high in the VA group and low in the coronary insufficiency groups. Instead of PWC_{130} another PWC_P value, where P refers to lower pulse or heart rates than those used in this study, might be useful.

The PWC_{max} (cf. Methods) may be regarded as an index of the behaviour of the subject in an experimental situation in which the subject is expected to perform physical exercise as well as possible. It is usually not possible to expect maximal performance from the patients, but it is likely that most of them worked fairly close to a real maximal performance. It is interesting to note that in those groups in which the PWC_{max} was low, also the PWC_{130} and PWC_{R13} were low. The last mentioned submaximal measures of physical working capacity were in most cases based mainly on observations obtained at a level of work load when subjective complaints had not become pronounced. In this connection it is interesting that a group of lumber workers ($n = 10$) who complained of pains in the knee joints and in the back rated the perceived exertion in relation to heart rate in a similar way to healthy workers.

The patients with vasoregulatory asthenia have a high heart frequency in relation to the rated value of perceived exertion. They are known to have a hyperkinetic circulation but normal blood pressures in the systemic and lesser circulation at rest as well as during exercise. The blood lactate during exercise increases less in relation to heart rate than in ordinary control groups and in patients with heart disease such as mitral stenosis (9). This may be one explanation for the perception of low exertion in relation to heart rate in VA patients, as the perception of exertion and blood lactate concentration during exercise seem to be closely connected in normal subjects (3).

In the same way a comparatively high blood lactate concentration may be one possible explanation of the fact that patients with coronary insufficiency rate the exertion high in relation to the heart rate. Patients with coronary insufficiency and a hypokinetic circulation (cf. 11) might be expected to have comparatively high blood concentration of lactate in relation to heart rate during exercise, as is the case in patients with hypokinetic circulation due to mitral stenosis (9).

It may be reasonable to assume that sensations related to the disturbed hemodynamic conditions in coronary heart disease should contribute to the results. It is known that these patients usually have a hypokinetic circulation with low cardiac output and stroke volume during exercise and a high blood pressure in the lesser circulation (11).

However, the patients with arterial hypertension, who have similar hemodynamic changes to patients with coronary heart disease (15), did not rate the exertion high in relation to heart rate. Nor was there a difference between group H_I, in which the hemodynamic change presumably was pronounced, and group H_{II} with less pronounced hemodynamic disturbance. Therefore sensations caused by this type of hemodynamic disturbance do not seem to have much influence on the relationship between rating of perceived exertion and heart rate. Nor should anginal pain be of much importance, as the work was usually interrupted soon after anginal pain appeared.

The signs and symptoms in patients with the vasoregulatory asthenia syndrome and patients with coronary heart disease may sometimes be quite similar (8). The difference in the rating of perceived exertion in relation to heart rate during exercise found between these groups of patients is therefore of differential diagnostic value.

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Perceived Exertion

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I. Introduction

In this chapter are reviewed the studies on perceived exertion since the first experiments in the late 1950s up to those published before 1973. Because these studies belong to a new area which differs from the more typical psychological studies of exercise and sport (e.g., those concerning personality, motivation, or psychomotor performance), and since no complete review of this field has ever been presented, this chapter is rather detailed. Both basic and applied studies are reported, some of which are directly and some indirectly related to sport and exercise.

Success in physical performance depends on several human factors which can be classified into two main categories: (*1*) physiological and morphological endowments, and (*2*) psychological resources including, among others, information and decision-making processes. Perceptual cues serve as the primary information source in physical performance. These cues enable individuals to regulate work intensity at a pace com-

patible with specified goals or the requirements of the activity. Thus, individuals engaged in exercise and sport receive "feedback" cues in the form of both general feelings of exertion and fatigue and also specific sensations varying in number and degree, such as muscular and joint pain, shortness of breath, and palpatations of the heart. The overall perception of exertion may be regarded as a *gestalt* of many sensations and feelings related to the work requirement.

A major area within the study of perception is psychophysics, i.e., the scientific field dealing with questions such as how the intensity of the perception grows with physical intensity. Analogous to the way in which physiological responses are described with mathematical functions, variations in perception have been measured and described mathematically. One prerequisite for basic psychophysical studies was the development of methods that may be classified as ratio-scaling methods, i.e., methods that give measurements on a ratio scale with a zero point and equidistant scale values, such as length and weight scales. Largely resulting from the research of Stevens and his collaborators at Harvard (Stevens, 1953, 1957, 1966) and also of Ekman and his collaborators in Stockholm (Ekman, 1958, 1959,1961a), such ratio methods were developed and applied to great many experimental studies. The methods were found to work well in most sense modalities (Stevens and Galanter, 1957; Stevens, 1971). During the 1960s, some studies were presented that criticized the new psychophysical methods as not being absolutely true ratio-scaling methods. However, it has been proven by physiological validations that they are good enough for rough general descriptions and comparisons among different modalities (Borg *et al.*, 1967; Franzen and Offenloch, 1969).

In medical diagnosis, subjective symptoms are used to identify a clinical syndrome and also to quantify roughly its intensity. The patient is asked how he feels; to locate the perceptions of discomfort or pain; and, to describe special sensations evoked during various kinds of stimulation. Subjective symptoms associated with physical work can also be studied in this way. As with objective (physiological) responses obtained from an exercise stress test on a treadmill or a bicycle ergometer, measurements of the subject's perceived degree of exertion can also be obtained. Perceptual data of this type can be viewed as a second class of stress indicators that complement the physiological indicators. A third class of stress indicators is the performance itself, e.g., a maximal performance or a preferred working intensity. These indicators constitute three parallel continua of effort: the perceptual continuum, the performance continuum, and the physiological continuum. The last continuum is often used to explain the variations in the others.

In *human factors* studies, one main objective is to discover methods to improve productivity, i.e., to decrease the work time and number of errors, but often an understanding of the subjective "costs" behind the performance is neglected. How hard and how difficult is the task or what is the psychological effort and strain? The same kind of problems are of interest in sport and exercise where perceptual cues are used to monitor the work intensity. The perception of exertion has been studied in many investigations since the end of the 1950s (Borg, 1971). These studies are part of a more general attempt to determine the various subjective variables involved in work performances and quantitative measurement of subjective symptoms: exertion, fatigue, discomfort, pain, satisfaction, etc. Such quantitative measurements are of interest in clinical diagnosis, in physical therapy and exercise prescriptions, in evaluations of performance capacity, and in many other applications.

Sensations related to internal functions and changes of body states, such as sensations during physical stress, have not been recognized as belonging to a separate sense modality. Bartley (1970) has pointed out the need to acknowledge a *homeostatic* and a *comfort* perceptual system. Bartley (1970), states that "we now have a number of receptors within the body that have been isolated, and functions attributed to them, but they have not been labelled as parts of a specific sense modality" (p. 158). Examples of these receptors are "carotid sinus receptors in the cardiovascular system," and "sensory endings in the walls of the venae cavae and pulmonary veins" (p. 158). After examining five classes of receptors and how they meet the criteria of inclusion in separate sense modalities, Bartley concludes that it is "obvious that these receptors participate in the form of body regulation that is known as homeostasis" (p. 159) and that there is a need to identify a specific homeostatic and comfort perceptual system. Perception of exertion is an important subjective response involved in these homeostatic–comfort systems.

II. Psychophysical Studies of Work of Short Duration

The first studies of dynamic muscular exertion concerned work of short duration (less than 1 min) on the bicycle ergometer (Borg and Dahlstrom, 1959, 1960). Experiments were performed to determine whether reliable measurements of perceived exertion could be obtained and if response–stimulus (*R-S*) relationships in this modality could be described by a power function. In most other modalities, studied with modern psychophysical ratio-scaling methods, power functions with exponents ranging from 0.33 (brightness) to 3.5 (subjective electrical intensity)

have been found to describe the variation of perceived intensity with physical intensity (Stevens and Galanter, 1957; Stevens, 1971). The experiments on perceived exertion during work of short duration showed very definitely that reliable measurements could be obtained.

In these studies, the production method known as *halving* was utilized. Subjects worked at a specified power level for a certain amount of time (e.g., 30 sec) and then, by using a throttle handle of the motorcycle type, adjusted the power level until it was perceived to be half as intense as the previous standard level. The deviations of the half-settings from the physical half-values reveal the size of the psychophysical exponent. If the subjects set a half-value above the physical half, an exponent greater than 1 is obtained. However, values set below the physical half reveal an exponent less than 1. The results of these experiments were later checked using other production methods, such as doubling, and estimation methods, such as ratio estimation and magnitude estimation (Borg, 1962).

All experiments revealed positively accelerated functions for the increase of perceived exertion with physical work load. The following equation was found to describe most data:

$$R = c(S + b)^n \tag{1}$$

where R is the intensity of the perception, c is the measure constant, S the physical intensity in kpm per minute (or watts), b is a basic constant, and n is the exponent. The value of the exponent was about 1.6 and the b value about 175 kpm/min (29 W). The reliability was computed by means of Hoyt's formula (Guilford, 1954) and was found to be high, $r_{tt} = .95$. The general equation may also be written:

$$R = a + cS^n \tag{2}$$

where a is the basic perceptual "noise" constant which is about 25% of the R value at $S = 300$ kpm/min.

Studies similar to those on the bicycle ergometer were performed by Stevens and Mack (1959) for subjective force of hand grip while squeezing a dynamometer. These ratio-scaling experiments revealed an exponent of 1.7 for subjective force which is about the same size as subjective effort while pedalling a bicycle. An exponent of 1.6 was later found by Eisler (1962) for subjective foot pressure.

To give further support to the finding that a positively accelerated function describes the R-S relationship, Borg *et al.* (1970b) utilized a new method first described by Marks and Slawson (1966). The method employs a system where the stimulus is continually varied as a function of time (t). The purpose of the experiment was to seek the S-t function

that corresponds to a linear relationship between R and t and is the inverse of the R-S function. Thus, if the psychophysical function is a power function, the subjective intensity increases linearly with time provided that the S-t function is a power function whose exponent is the reciprocal of the psychophysical function.

The experiment was performed on 20 male subjects at a pedalling rate of 60 to 65 rpm. During each test the subjects were instructed to pedal for 30 sec during which time the work load was continually increased from 0 to 2000 kpm/min. A special ergometer was used with an electronic braking system (Borg *et al.*, 1971b). The work load on this ergometer can be increased or decreased from 0 to 500 units/sec and the variation of the load can be adjusted to one of the following exponents of the R-S function: 2.5, 2.0, 1.5, and 1.0. Each subject was tested twice under each of four S-t conditions (0.4, 0.5, 0.7, and 1.0 which correspond to the foregoing R-S functions). Each test included both as ascending and descending series. Immediately following each test, the subjects reported their perception of the change in work load according to the following three alternatives: (*a*) the work load changed most rapidly at the beginning; (*b*) the work load changed constantly; or (*c*) the work load changed most rapidly at the end of the work. The experiment showed that when the work load increased as the 0.4 or decreased as the 0.6 power of time the variation was judged to be linear. Exponents of the corresponding psychophysical functions were 2.5 and 1.6, whereas the means for the combined ascending and descending series were 1.8 for test 1 and 2.0 for test 2. This method, which used only three rating categories and no numbers, revealed slightly higher exponents than other methods but confirmed the presence of positively accelerated functions.

III. Psychophysical Studies of Work of Longer Duration

For work of longer duration, as during an exercise stress test with stepwise increases in work loads (e.g., 4–6 min per load), the demands on the individual are somewhat different than during short time work. The time per work load is dictated by the time necessary to allow cardiovascular functions to attain a steady-state level. Several studies of perceived exertion during bicycle ergometer work have been performed utilizing a typical stress-testing method. Production methods such as halving and doubling cannot easily be applied in longer work because of the memory errors and adaptation effects. Instead, ratio estimation and magnitude estimation methods have been used (Borg, 1961, 1962). Positively accelerated functions were found with exponents around 1.2 if no con-

sideration is given to any additional constants. However, the linearity in log-log coordinates is much better when a constant of about 200 kpm/min is added to the stimulus intensity, giving an exponent $n = 1.6$. An estimate of reliability was obtained as in the first experiment (Section II) resulting in $r_{tt} = .91$.

When describing the results of biological experiments it might in some cases be preferable to include two constants as opposed to a simple power law, so that the general function may be written:

$$R = a + c(S - b)^n \tag{3}$$

where R is the intensity of the response and a is a constant for the basic perceptual "noise" level which, together with the physical constant b, describe the starting point of the curve (Borg, 1961, 1962). An example of a physiological variable that can be described by this general function is the increase of lactic acid concentration with increasing work loads on the bicycle ergometer (>50% of $\dot{V}O_{2\ max}$) in well-trained subjects (Borg, 1962). This general function has also been proposed by Mountcastle *et al.* (1963).

When describing the psychophysics of muscular work the best function seems to be one with a positive a value and with $b = 0$. This same function has been proposed by Ekman (1961a,b) and applied to the variation of taste perception.

Since 1953 when Stevens proposed the power function as a general 'law' to describe psychophysical functions, several modifications of its form have been proposed. For a review of some of these changes the reader is referred to an article written by Marks and Stevens (1968).

Hueting (1965) and Hueting and Sarphati (1966) also studied perceived exertion (or fatigue as they preferred to call it) during bicycle ergometer work and found mainly positively accelerated functions. They used a method in which the subject could set a value on a 90-point graded scale by varying a voltmeter pointer. Because of a slight "ceiling effect," their functions were more linear and for practical purposes they adapted linear regression curves to the data. Another study on subjective effort during bicycle ergometer work was performed by Sjoberg (1968). He found an exponent of 1.6.

In a recent study by Borg (1972a) a check of the general psychophysical function was performed. Individual functions for each of 28 subjects were calculated for work on a bicycle ergometer. A new method was used in which subjects estimated the degree of perceived exertion in relation to their notion of a maximal exertion which was designated 100. Twenty-seven of the subjects exhibited positively accelerated functions with most exponents around 1.5. The following equation describes the data of the

largest group of subjects who managed to work up to 1200 kpm/min but less than 1500 kmp/min:

$$R = 4 + 0.001S^{1.6} \tag{4}$$

where S is measured in kpm per minute and the noise constant 4 denotes 4% of maximal exertion (100%). The basic constant is of the same magnitude as those obtained in previous studies.

The inclusion of the constant a should have meaning in addition to the improvement in linearity it offers on a log-log plot. Therefore, a study was performed by Borg (1972c) to determine whether other reasons could be found to defend the inclusion of the constant a. Subjects were instructed to estimate their perceived exertion while sitting on a bicycle ergometer without pedalling. Most subjects reported a small but positive value of about 4 to 5% of their notion of maximal exertion. Also, the subjects estimated their degree of exertion during the recovery period following heavy work. Even as long as 1 hour after termination of work, all subjects reported a value of about the same size as prior to work.

From a physiological point of view, it may be predicted also that there is a general feeling of exertion just by being active in routine pursuits during the day. Some people might be in a state of exertion that is rather high while some might be close to a resting "zero." When subjects come to a laboratory to take part in an experiment, they usually are in an increased state of arousal as reflected in such measurements as heart rate, blood pressure, and possibly other physiological stress variables which may be associated with the perception of exertion. Thus, the inclusion of constant a seems justified (Borg, 1972a,c).

IV. Studies of Individual Differences

A problem of concern is that the psychophysical ratio-scaling methods are not applicable in most differential studies, e.g., in clinical studies where interindividual comparisons are desired. Ratio methods, developed for general comparisons within and between different modalities, give only ratios between percepts and not direct intensity levels, e.g., of the degree of physical stress. Borg (1961, 1962) developed a model to make interindividual comparisons possible. In the model it is assumed that the subjective range, from the basic perceptual noise level to a maximum intensity level, is about the same for all subjects in spite of the fact that the stimulus range (or the performance range) might differ very much. If we denote the terminal (maximal) level with the subscript T, the mea-

sure constant c in Eq. (2) can be solved for each individual in the following way:

$$c = \frac{R_T - a}{S_T{}^n} \tag{5}$$

where $R_T - a$ is assumed to be equal for all subjects, and S_T and n are determined experimentally for each individual. In recent studies by Borg (1970a, 1972b) this method for interindividual comparisons has been applied to other kinds of "interprocess comparisons" such as comparisons between modalities and between variables belonging to different scientific disciplines. According to the model, predictions can be made about the degree of physical stress from such different variables as perceived exertion for one subject, heart rate (HR) for another, and blood lactate for a third.

To obtain simple direct measurements of the degree of perceived exertion, according to a method that can be used by most everyone, not only by subjects who have a superior capacity to handle numbers expressed as ratios, a simple rating method has been developed. Several different scales have been tried but the one most often in use is the scale for rating perceived exertion (RPE scale), which varies from 6 to 20 to approximate one-tenth of HR (from 60 to 200); see Table I.

In a study by Borg (1962) the ratings of perceived exertion gave a very high correlation with absolute HR ($r_{xy} = .85$) when the work intensity was varied from light to heavy work. With the same work load the correlations were fairly low (from .20 to .50), especially at low loads.

TABLE I
THE RPE SCALE FOR RATINGS OF PERCEIVED EXERTION

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

The RPE scale was constructed to follow HR for work on the bicycle ergometer and for healthy middle-aged men performing moderate-to-hard work so that the HR should be about 10 times the RPE value.

In a study by Borg (1972a) subjects were instructed to rate their exertion as a percentage of their notion of maximum exertion ($R\%$). A correlation of .31 was obtained for work at 600 kpm/min and .56 for 900 kpm/min. The corresponding correlations between HR's and ratings according to the RPE scale were .65 and .68.

V. Estimates of Physical Working Capacity from Perceived Exertion

The HR for a certain work load is a direct measurement of the degree of physical stress and an indirect one of the physical working capacity (W). Analogous to the application of HR measures, ratings of perceived exertion may be used to estimate W. To obtain reliable and valid measurements, several work loads should be administered with stepwise increases as in the tests designed by Sjostrand (1947) and Wahlund (1948).

The Sjostrand test usually continues until the subject has reached a certain predetermined HR level, e.g., 170 beats/min for young men and 150 beats/min for middle- to old-aged subjects. In several studies where ratings of perceived exertion have been collected at the same time as HR, estimates of the individuals' working capacity have been obtained in the form of the work loads at a certain degree of perceived exertion. The construction of the rating scale makes it very simple to calculate the work loads that the subject can manage at a reference level of, for example, 17 on the RPE scale. Since the rating of 17 roughly corresponds to the HR of 170 for most subjects between 25 and 50 years of age the W_{R17} (the work load at a rating of 17) corresponds to W_{170} (the work load at a HR of 170 beats/min).

The reliability of the W measurements of physical working capacity based on ratings of exertion were compared to those based on HR (Borg and Linderholm, 1970). In a group of 54 healthy male subjects, intratest correlations were determined by correlating two different W_{130} measurements: one obtained by using the HR from 300 and 900 kpm/min, and the other by using the HR from 600 and 1200 kpm/min from the same test. A reliability coefficient of .91 was obtained. In the same way the reliability of the W_{R13} measurements was calculated and found to be .92. The error of a single measurement is thus small or about 5% of the mean value of 1200 kpm/min. Test–retest reliability coefficients were also determined in a mixed group of 9 male and 10 female patients and a group of 12 male and 5 female healthy subjects (Borg and Linderholm, 1970).

The second test was carried out 2–4 weeks after the first test, a fairly long period, to minimize the effect of memory on the rating of perceived exertion. The W_{130} and W_{170} test–retest coefficients were .93 and .98, respectively, in the patients and .88 and .97, respectively, in the healthy subjects. The corresponding W_{R13} and W_{R17} coefficients were .80 and .94, respectively, in the first group and .91 and .98, respectively, in the second. These coefficients show that the reproducibility, based on repeated measurements, is about as good for the W_R measurements as for the W_{HR} measurements.

In a study by Borg (1962) of the working capacity of lumber workers ($N = 57$) both measurements, W_{170} and W_{R17}, were obtained. As a rough criterion of the performance capacity, wages from piece work were used. The study showed that working capacity according to the ratings showed a correlation of .54 with the wages, whereas the working capacity according to the HR gave a correlation of only .23. These correlations should not be taken too literally in this connection as the group was very heterogeneous in maximal HR. Furthermore, some subjects did not reach a HR of 170 beats/min. The study shows, however, that the predictive power of the estimates of working capacity based upon ratings of exertion might be better than those based upon the HR, especially in age-heterogeneous groups.

In a study by Borg and Linderholm (1967) measurements of physical working capacity according to W_{170}, W_{130}, and W_{R17} were compared for different age groups. The W_{170} and W_{130} measurements increased slightly with increasing age in the group of lumber workers ($N = 57$) but was rather constant with increasing age in the mixed sample (according to occupation) ($N = 216$). The working capacity estimated from the W_{R17} ratings was more or less independent of age in the group of lumbermen, but decreased markedly with increasing age in the mixed group. Since we know that the maximal HR decreases with age, the W values estimated from ratings, in this case, probably give a better estimate of the true working capacity than those calculated from the HR. The fact that the W_{R17} measurements stayed constant with age in the group of lumbermen was explained by the fact that they belonged to a selected group of men who do the same kind of daily, hard, physical work with similar high demands of endurance fitness.

VI. Clinical Studies

Ratings of perceived exertion are now collected together with physiological data during ordinary work tests at several departments of clinical

or work physiology in Sweden and some other countries. The relation between HR and ratings was calculated for patients with coronary heart disease, patients with arterial hypertension, and patients with vasoregulatory asthenia syndrome (Borg and Linderholm, 1970). In comparison with a healthy control group of the same age, the patients with the vasoregulatory asthenia syndrome rated the exertion to be less in relation to the HR, especially at low intensity levels. The results for the group of patients with arterial hypertension were somewhat similar to the group with vasoregulatory asthenia, but the difference was less marked. The third group of patients with coronary heart disease rated the exertion to be higher in relation to heart frequency, particularly at high rating levels. In all the groups of patients studied, there was a smaller increase in HR in relation to a given increase in ratings of perceived exertion than in the groups of healthy control subjects.

Studies have recently been performed on patients at a rehabilitation center in Johnstown, Pennsylvania (Borg *et al.*, 1969; Borg, 1970b). A group of mentally retarded male subjects, 16–23 years of age, a mixed group of male psychiatric subjects, aged 16–25, and a group of older male psychiatric subjects, aged 25–36, performed a physical work test on the bicycle ergometer during which HR and perceived exertion were recorded. The results of the test showed that the group of young patients as a whole had about 15% lower working capacity than a group of University of Pittsburgh students of the same age and about 40% lower than a group of lean active and a group of heavy active students athletes at State College, Pennsylvania (Skinner *et al.*, 1969). Compared to a group of heavy sedentary young men at the State College, the group of young patients had about 30% lower working capacity, and compared to a lean sedentary group the work capacity was about the same. The perceived exertion (RPE scale) in relation to work load was higher in the groups of patients than in the normal reference groups. The low physical working capacity and the high degree of subjective stress of these groups of patients probably result from institutionalization and less adequate programs for endurance and fitness training.

The high correlation found between HR and perceived exertion is usually not so high in mixed groups of patients. Since the rating of perceived exertion probably depends on many different kinds of body sensations the kind of disease a patient has may strongly influence his rating. Some patients get sensations of pain and discomfort primarily in the legs whereas others may have breathing difficulties or sensations of chest pain. The overall ratings of exertion then denote different kinds of physical stress, lowering the correlation with HR (Borg and Linderholm, 1970).

Ratings of perceived exertion have also proved useful in clinical tests

if there is some doubt when to interrupt the tests. For example, a HR of 170 is often used as a criterion for stress test termination; however, because of variability in maximal HR this level may be very stressful for some subjects and only moderately stressful for others. In these cases, the ratings compliment the HR and give cues for interrupting work tests and also for making changes in the stepwise increase of the work loads (Borg and Dahlstrom, 1962; Borg, 1962, 1970b).

VII. Psychophysiological Studies of Perceived Exertion

Ultimately, attempts to understand human performance cannot be successful without the integration of scientific efforts of serveral fields. Psychophysiological studies of perceived exertion lie at the interface of at least two human sciences, i.e., psychology and physiology. It is here, at this interface, that man's adaptation to exercise and sport must be studied more thoroughly. Several initial investigations have been conducted but many more are necessary. In this section are reviewed studies that have examined the relationship between various physiological parameters and perception of exertion during physical exercise.

With few exceptions, the psychophysiological studies reported here have utilized the category scale developed by Borg (1962) to obtain ratings of perceived exertion (RPE). As stated previously, the scale was developed so that interindividual comparisons could be made in applied studies, particularly when using the bicycle ergometer as a testing mode. The objective was to construct a scale capable of measuring subjective physical strain. Since no suitable psychological variable existed that could validate the scale, a physiological strain variable was used as the validation criterion. Heart rate was selected as the criterion since it is known as a good indicator of metabolic strain and is widely used in bicycle ergometer studies.

By trial and error during several studies the numerical values and adjective—adverbial anchor expressions were manipulated on the scale so that RPE had a linear relationship with HR. The 6–20 point scale was set so that it generally matched the HR range of most young subjects, i.e., 60–200 beats/min. Therefore, it would be possible during working capacity tests on the bicycle ergometer to predict HR by the following simple equation:

$$HR = RPE \times 10 \quad (6)$$

This equation was constructed more for the purposes of illustrating the

validation of the scale than for exact predictive use although it has been found to function relatively well, e.g., in a large group of middle-aged men (Grimby *et al.*, 1972).

It has never been suggested that there is a causal relationship between RPE and HR. However, correlations between .80 and .90 computed over a wide range of work loads demonstrate that a high percentage of common variance is shared by perceived exertion and HR. This is not surprising since the scale was constructed with such a relationship in mind. It has been suggested that this relationship may be false since it was obtained from bicycle ergometer test data in which work loads were administered nonrandomly from low to high. Unpublished studies at the University of Pittsburgh and Pennsylvania State University have shown, however, that the relationship remains when work loads were administered in random order. Because of the known linear relationship between HR and oxygen intake ($\dot{V}O_2$), it is not surprising that RPE is also linearly related to $\dot{V}O_2$ (Noble and Borg, 1972). Thus, it can be said that, in so far as HR and $\dot{V}O_2$ reflect physiological strain, RPE can also be used as a strain indicator.

The effect of possible cultural differences on the HR–RPE relationship has been considered. In the bicycle ergometer studies of Sherman *et al.* (1968) and Skinner *et al.* (1969) on university-age American males and by Bar-Or *et al.* (1972) on middle-age American males the same linear relationship between RPE and HR was found as with Swedish samples.

Under certain conditions, as would be expected, the RPE–HR relationship can be disrupted. Not that the linearity is removed but the regression line is displaced from that observed under "normal" conditions. One example is seen when subjects exercise under the influence of autonomic nervous system blocking agents. At the same HR level, administration of propranolol increases the perception of exertion compared to control levels; atropine administration lowers the RPE at the same HR level (Ekblom and Goldbarg, 1971).

Another example is subjects who exercise under the influence of increased environmental heat. Pandolf *et al.* (1972) found no significant differences in RPE during equal work load conditions even though HR had been significantly increased by environmental heat. Ratings were not affected by HR but by alterations in work load when increments were greater than 200–300 kpm/min.

Hypnotic suggestion was utilized to examine its influence on perceptual and metabolic responses to work on the bicycle ergometer. Ratings of perceived exertion were found to follow hypnotic suggestions of light, moderate, and heavy work even though subjects were always working

at 600 kpm/min (50 rpm). Heart rate during the heavy work suggestion was found to be significantly higher than during light work suggestion (Morgan *et al.*, 1973).

Many studies have shown that maximal HR decreases with age. This implies that the relation between RPE and HR also changes with age. In a study by Borg and Linderholm (1967) this relationship was examined in four different age groups of Swedish lumber workers and a mixed group of men of different occupations. It was found that the older subjects rated the degree of exertion to be higher in relation to HR than the younger subjects. The change in the HR–RPE relationship clearly reflected the decrease of the maximal HR with age.

Possible sex differences can be examined from the data of some studies. Borg and Linderholm (1970) found that females on the average had a slightly higher heart rate than males at equal perceptual ratings. The difference was not statistically significant except at low ratings ("rather light" work). Henriksson *et al.* (1972) found that female subjects perceived their exertion (concentric and eccentric work) both at given work loads and oxygen consumptions to be greater than for male subjects. Michael *et al.* (1972) studied 4 male and 4 female subjects to determine physiological responses when subjects subjectively estimated effort on the treadmill and bicycle ergometer which would "exhaust" them in 15 min. The men chose work levels that resulted in HR's and respiratory quotients (RQ) similar to those of the women, whereas oxygen consumption and oxygen debt was double that of female subjects.

Physiological–perceptual responses to physical training have been studied by several investigators. Linderholm (1967) studied Swedish military conscripts before and after 4 months of training. Both HR and RPE were reduced approximately 20% at the same submaximal work load following training. Essentially the same finding was reported by Docktor and Sharkey (1971). Ratings at a HR of 150 were not altered following a 5-week training program. However, the time to reach a HR of 150 was significantly increased, thus it occurred at a higher work load. In another investigation at given submaximal $\dot{V}_{O_2}$ levels, RPE was reduced 1.5–2.0 points following training (Ekblom and Goldbarg, 1971). Since maximum $\dot{V}_{O_2}$ increased with training, RPE differences were not observed when $\dot{V}_{O_2}$ was expressed in "relative" terms, i.e., as a percent of maximum $\dot{V}_{O_2}$. The HR–RPE relationship seems to remain unchanged with training, but the $\dot{V}_{O_2}$–RPE relationship is altered in terms of raw values but not in relative terms.

The foregoing findings have also been observed in other situations. Skinner *et al.* (1969) studied young men between the ages of 17 and 24 who differed in activity level and body size. At the same submaximal

work loads the active subjects had lower HR's and RPE's than sedentary subjects, and heavier subjects had a lower HR than lean subjects but there was no difference in RPE. However, differences between activity and body size subgroups were not found at given percentages of maximum working capacity. Also, RPE was found to be higher for cycling than for treadmill running at given submaximal $\dot{V}_{O_2}$ levels but was not different at relative $\dot{V}_{O_2}$ levels (Ekblom and Goldbarg, 1971). Undoubtedly, in the study, reviewed in the foregoing, regarding females who rated significantly higher than males at given work loads and oxygen consumptions, no significant differences would have been observed if relative values had been taken into consideration.

In two investigations RPE has been examined when HR, $\dot{V}_{O_2}$, and power output were held constant experimentally. The bicycle ergometer provides a unique opportunity for these manipulations since revolutions per minute and resistance can be adjusted to hold power output, oxygen consumption, and HR constant while still providing subjectively different exercise experiences. Henriksson *et al.* (1972) studied concentric and eccentric work at two pedal frequencies (30 and 60 rpm). These investigators found that, at the same power output, 30 rpm was perceived as greater than 60 rpm for both types of work. The difference was also observed when compared at given oxygen consumptions. Pandolf (1973) studied the same problem, using concentric work only, and found that 40 rpm work was subjectively judged to be more stressful than 60 and 80 rpm work. In these experiments some factor(s), other than HR, $\dot{V}_{O_2}$, and power output, must account for the increased exertional perception at the lower pedal frequencies. Henriksson *et al.* (1972) speculate that muscle tension may be a factor in the higher exertional ratings since it must be doubled during the contraction to sustain the same power output at half the frequency. Pandolf (1973) points to the involvement of local factors, possibly muscle and joint discomfort and/or anaerobic products, as contributing to this exertion-rating phenomenon.

Michael and his collaborators (1972) in several investigations have utilized psychophysical production methods to identify possible physiological cues utilized in the subjective evaluation of work effort. These methods involved asking subjects to equate effort subjectively in two separate exercise situations by manipulating work load. Physiological variables were recorded when the tasks were judged by the subjects to be equal. Ten female subjects ran on a treadmill at a speed they selected previously to "tire" them in 15 min and later repeated the same effort on a bicycle (Michael and Hackett, 1972, p. 216): "The absolute value of oxygen uptake, ventilation and heart rate did not indicate to the subject that the physiological strain was similar, since all these measure-

ments were lower on the bicycle during the selected work effort." Oxygen debt was said to be unrelated since it was double on the treadmill to that on the bicycle. These authors suggest, as have others in this review, that, although absolute values were different, relative strain was equal.

Michael and Eckardt (1972) compared level and slope (10%) running using the same techniques. The only significant differences found were with RQ's and ventilatory volumes, which were higher during slope running. It was suggested that the similarity in HR implicates this variable as a cue to work selectivity. Oxygen debt and local feeling of discomfort were also implicated. "The only reason then for the increased ventilation and RQ could be a proprioceptor response of the leg muscles or the fact that the arms are used more and hence, more muscle activity raises the ventilation." (Michael and Eckardt, 1972, p. 109). All subjects regardless of their state of training ($N = 3$, trained; $N = 3$, untrained) selected loads which were 80% of maximum.

Again, using a production method, Michael *et al.* (1972) studied physiological responses during subjectively equated work tasks, which would "exhaust" the subjects in 15 min, i.e., progressively incremented loads while walking 3.5 mph on a treadmill (2%/2 min) and cycling on a bicycle ergometer (150 kpm/2 min). Heart rate, $\dot{V}_{O_2}$, oxygen debt, and ventilation were similar when work efforts were judged to be qeual. "The most consistent cue, regardless of sex or type of exercise, was a heart rate level of between 165 and 180 and R.Q. of 0.90" (Michael *et al.*, 1972, p. 451). Since the lower leg muscles were used in much the same way in these two forms of exercise, it was suggested that the similarity in HR may be due to local muscular strain.

Another study that suggests local muscle involvement in the perception of exertion was conducted by Noble *et al.* (1973). Perceptual and metabolic responses to walking and running at similar velocities between 2.5 and 5.5 mph were investigated. Perceived exertion exhibited a similar pattern to HR, i.e., both curves intersected and reversed. However, the intersection point for HR (4.92 mph) was significantly higher than for RPE (4.31 mph). This led the authors to propose that local muscular discomfort encountered at higher walking velocities was responsible for the earlier perceptual intersection.

Cain and Stevens (1971) utilized constant effort techniques to study perceptual responses during isometric muscular work. Subjects were asked to maintain a constant level of subjective effort over time on a hand grip dynamometer. Force curves were found to decay with an early fast component followed by a slow component in order to maintain constant effort. It was suggested that the fast component was a function of effort signaled by mechanoreceptors in the tendons or skin; the second component was thought to be due to buildup of noxious metabolites produced by muscle activity.

In those experiments in which the so-called central metabolic factors (HR and $\dot{V}_{O_2}$) could not be implicated, it is possible that anaerobic factors such as lactate production and oxygen debt were involved. Stamford (1973) studied bicycle ergometer work at different pedal frequencies but equal power outputs and found that lactate and oxygen debt did not change even though RPE was significantly higher at 40 than at 60 rpm. Arm exercise is known to produce higher lactates than leg exercise at the same oxygen consumption level (Astrand *et al.*, 1968). Ekblom and Goldbarg (1971) found that, at given absolute or relative $\dot{V}_{O_2}$ levels, RPE is higher in arm than leg work. However, when blood lactate concentrations were used, RPE for arm and leg work was the same. Likewise, when cycling and running were compared, RPE was the same for given blood lactate concentrations. Gamberale (1972) studied lifting of weights, an arm exercise, and bicycle ergometer work, a leg exercise. At approximately the same $\dot{V}_{O_2}$ level (e.g., 0.83 for arms and 0.89 liter/min for legs), blood lactate levels were 3.2 mmoles/liter for arms and 1.8 mmoles/liter for legs with corresponding RPE values 12.9 and 9.9. These studies suggest that lactate production may be involved in exertional perceptions when comparisons are made between muscle groups. However, this does not seem to be the case when the same muscle groups are tested at differing pedal frequencies. It should also be noted here that most physiological variables, for example HR and $\dot{V}_{O_2}$, grow linearly with work load while perceived exertion, when ratio-scaling methods are utilized, grows according to a positively accelerating function. Since blood lactate is one of the few physiological variables that follows the same kind of function, indirect support is obtained for a relationship between perceived exertion and blood lactate.

Catecholamine excretion has been proposed by Frankenhaeuser *et al.* (1969) as a factor in perception of exertion during heavy work. Little change in catecholamines was recorded when effort was judged to be "extremely light," "very light," or "fairly light" on an RPE scale. After the midpoint of the scale, adrenaline increased 84% and noradrenaline 42% compared to control observations. Increases in noradrenaline were identified as a function of the cardiovascular regulatory system, whereas increases in adrenaline were thought to be due to mental stress and unpleasantness associated with heavy physical work. Docktor and Sharkey (1971) observed a decrese in vanillinemandelic acid (VMA), an estimate of urinary catecholamine excretion, after a 5-week training program. It was suggested that the VMA decrease indicated a decrease in adrenaline or the mental stress of the work test. Observations that catecholamines

increase during heavy work, however, do not explain the mechanism for exertional perception increases during less intense work. It is again important to note that catecholamine excretion, as was true for lactate production, grows as a positively accelerated function which is also true of perceived exertion measured by ratio-scaling techniques.

Borg (1962) has attempted to explain the very complex nature of perceived exertion. He suggests that contributory factors consist of:

> sensations from the organs of circulation and respiration, from the muscles, the skin, the joints etc. . . . 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 (Borg, 1962, pp. 10–11).

The investigations of Ekblom and Goldbarg (1971) led them to propose a two-factor model to explain variations in perceived exertion during different forms of physical work. The authors suggest the existence of both local and central factors. The presence of a local factor, i.e., feeling of strain in the working muscle, seems to fit the data when arm and leg work and cycling and running were compared. "In work with small muscle groups the local factors seem to be dominant, while work with large muscle groups will tend to stress the pumonary ventilation and circulation and thus give an addition to the local strain" (Ekblom and Goldberg, 1971, p. 405).

Henriksson *et al.* (1972, p. 543) state that "the perception of exertion consists of an integration of a number of signals originating in a variety of receptors and locations in the body and, further, that the combination is dependent in great part upon the particular conditions of the exercise" Mechanoreceptors, baroreceptors, thermal and pain receptors were implicated as possible sites of signal source.

Any conclusions at this early stage in the study of physiological–perceptual interaction would obviously be somewhat speculative. However, the investigations reviewed herein can serve as a logical basis for the statement of hypotheses and considerable future work.

VIII. Perceived Difficulty

A concept closely related to perceived exertion is the concept *perceived difficulty*. The effort a man has to exert in solving a problem or achieving

good physical performance reflects partly the difficulty of the task. Different kinds of performances vary in difficulty, and to understand the "subjective costs" to the individual who is performing a task requires quantitative measurements of the degree of difficulty involved. Also, when classifying and discriminating among different tasks, measurements of their difficulty are of importance.

Psychophysical studies of subjective difficulty have been performed in a series of experiments concerning mental tasks. In an initial study by Borg and Forsling (1964), it was shown that the same kind of methods described in the preceding sections and used to measure perceived exertion of physical performance can be used to measure perceived difficulty of mental performances. Many different kinds of mental tasks have since been studied (Borg *et al.*, 1971a; Bratfisch, 1972). In most experiments the perceived difficulty has been found to grow linearly with the physical difficulty according to the usual psychometrical measurements (based on solution frequencies). In most cases, high correlations were obtained between subjective and objective measurements of difficulty.

In a psychomotor experiment, which involved learning a two-hand psychomotor task, the perceived difficulty was studied as a function of training (Bratfisch *et al.*, 1970). The subjects were instructed to try to do their best in seven successive trials on a wire labyrinth and were asked to estimate the degree of difficulty of each trial. The results of the experiment showed a decrease (improvement) in performance time by 43% and a decrease in perceived difficulty by 48%. The trend for both functions was fairly similar. Although the subjects were instructed to try to perform at an effort of 100% during each trial, the difficulty of the task was not perceived to be the same, but dropped markedly. The correlation between perceived difficulty and performance time was as high as .96, suggesting that the estimation of difficulty, to a great extent, might have been based on the perception of time.

IX. Summary

In exercise and sport, medicine, and human factors engineering it is important to have access to good measurements of the degree of physical stress to which the individual is exposed. Physiological stress measurements have proved very reliable and valid, and within the science of human physical activities or "ergology," as this field tentatively may be named, physiological studies have been predominant. Another kind of measurement of interest in this connection is the perceptual stress measurements. These complement the physiological ones.

When studying man at work the interest has too often been focused on ergonomic efficiency criteria such as the speed and the number of errors in a performance. During the last years the interest however, has grown concerning the "subjective costs" to the individual. How hard and difficult is the work for the man himself? What does he perceive in the form of physical stress of importance for his adaptation and job satisfaction?

In medicine, subjective symptoms are used for diagnostic purposes. The patient is asked about perceptions of discomfort or pain, and which special sensations are evoked during various kinds of stimulation. Subjective symptoms associated with physical work are now also studied in this way.

In exercise and sport it is very important for the athlete to get correct information from various perceptual cues. The perception of exertion is such a perceptual cue of value also for the regulation of proper work intensities.

The overall perception of exertion may be regarded as a *gestalt* or configuration of various sensations and feelings of effort and stress due to physical work. Peripheral sensations from the muscles and joints and central sensations from the cardiovascular system, etc., form together with previous experiences the perception of exertion. The intensity of the perception and, also to some degree, its quality may then vary depending upon how large muscle groups are involved and how long the work has been performed.

Most experimental studies of the perception of exertion have been carried out during the last 15 years. The first experiments concerned psychophysical relations: How does the perception of exertion (R) grow with the physical work load (S), e.g. work on a bicycle ergometer? The studies have shown positively accelerated functions with exponents of about 1.6 for both short-time work (less than 1 min) and long-time work (about 6 min) on the bicycle ergometer.

The perception of exertion is a direct indicator of the degree of physical stress and an indirect one of the physical working capacity. Measurements of working capacity have thus been calculated from ratings of perceived exertion during ergometer work and found to be both reliable and valid. They are closely related to the absolute amount of work (W) a person can do. Changes with age that do not affect the W_{170} measurements do affect the corresponding W_R measurements, i.e., the measurements of working capacity calculated from a work load that a subject can manage at a certain degree of perceived exertion (R). The W_R measurements thus follow closely the changes with age of the W_{max} measurements and the W measurements calculated from relative heart rates. The predictive power of performance capacity has been found to be equally good from

measurements calculated from perceived exertion as to those calculated from heart rates.

Several clinical studies of perceived exertion have now been performed showing its value in both differential diagnosis and therapy. In many work tests, ratings of perceived exertion are now used to give additional information of when to interrupt the tests. The relation between ratings and heart rates are used to elucidate clinical symptoms and in some cases also the degree of work motivation. In therapy and exercise prescription the perception of exertion is used to modify the work intensity that is just right for the individual. As a complement to pulse-counting, the feeling of exertion may thus guide the individual to regulate the intensity of the exercise.

Several psychophysiological studies have been performed and many are in progress. The general idea of these studies is to "explain" the variation in perceived exertion with work load and the differences between individuals and kinds of movements, by looking at the corresponding physiological variables of relevance. Some of these studies attempt to find causal "explanations" but most of them try to find statistical correlates. A strong correlation has thus been found between perceived exertion and heart rate for most kinds of work. Other physiological variables that hitherto have been studied are: oxygen consumption, breathing frequency, body weight and height, adrenaline and noradrenaline, blood lactate, and blood pressure.

Most of the studies of perceived exertion deal with the concept of exertion as a *gestalt* of many sensations. It will be of interest to try to analyze the various dimensions of exertion as related to different parts of the body, length of time of work, and different clinical symptoms. Another question concerns the further development of practical methods for exercise prescriptions and also work tests. Psychophysical scaling problems also have to be studied further to establish the true variation of perceived exertion with other variables, e.g., speed of movement or mode of exercise.

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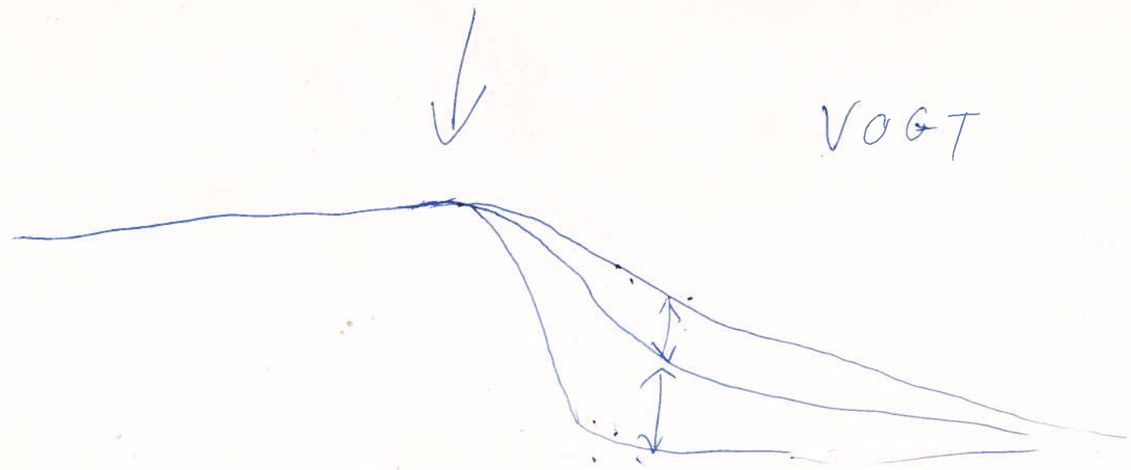
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