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Psychophysical bases of perceived exertion

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ABSTRACT

BORG, GUNNAR A.V. Psychophysical bases of perceived exertion. *Med. Sci. Sports Exercise*, Vol. 14, No. 5, pp. 377-381, 1982. There is a great demand for perceptual effort ratings in order to better understand man at work. Such ratings are important complements to behavioral and physiological measurements of physical performance and work capacity. This is true for both theoretical analysis and application in medicine, human factors, and sports. Perceptual estimates, obtained by psychophysical ratio-scaling methods, are valid when describing general perceptual variation, but category methods are more useful in several applied situations when differences between individuals are described. A presentation is made of ratio-scaling methods, category methods, especially the Borg Scale for ratings of perceived exertion, and a new method that combines the category method with ratio properties. Some of the advantages and disadvantages of the different methods are discussed in both theoretical-psychophysical and psychophysiological frames of reference.

PERCEIVED EXERTION, RATIO SCALES, CATEGORY SCALES

Need of Methods to Quantify Symptoms

During recent decades we have become more interested in how people feel, what aches and pains they have, and how difficult they perceive their work to be. Most scientists and practitioners in the health sciences agree that it is important to understand subjective symptoms and how they relate to objective findings. Therefore, we must develop methods to quantify these subjective symptoms. These methods should be equally applicable to most people regardless of gender, age, circumstances, and national origin.

Perceived Exertion as an Indicator of Physical Strain

The individual's perception of exertion during physical work is interesting when studying man at work or leisure-time activities, in diagnostic situations or exercise prescriptions, and in epidemiological evaluation of daily exercise intensities. People primarily seek medical care because they feel ill, not for treatment of a specific disease. Medical assistance is most frequently sought by patients who have noted a severe decrease of their physical working capacity and a subsequent subjective strain.

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In my opinion perceived exertion is the single best indicator of the degree of physical strain. The overall perceived exertion rating integrates various information, including the many signals elicited from the peripheral working muscles and joints, from the central cardiovascular and respiratory functions, and from the central nervous system. All these signals, perceptions, and experiences are integrated into a configuration or "Gestalt" of perceived exertion.

Psychophysical Ratio-Scaling Methods

The need to devise better methods to measure perceptual intensities led to the development of several so-called "ratio-scaling methods" (13,14). It was the scientists' goal to develop methods that had the same metric qualities as methods used in physics and physiology, i.e., methods with an absolute zero and with the same distance between all scale values. One such method is "ratio production," in which subjects are asked to increase or decrease a certain variable stimulus until it is perceived to be a certain fraction or multiple of a standard stimulus. For example, in an experiment concerning brightness, taste, or loudness, each subject is asked to set the variable stimulus to be half or twice as intense as a certain standard stimulus. When this is performed throughout the whole intensity continuum, possibilities can be obtained to construct a psychophysical scale, i.e., a scale describing how the perceived intensity varies with the actual physical intensity.

A simple example taken from everyday experiences demonstrating the ratio-production method involves one's perception of speed while driving a car. The subject drives 50 miles/h and then is instructed to decrease the car's speed until he/she perceives it to be half as fast. The actual speed is really about 35 miles/h—very much above the physical half. This is in accordance with a power function with an exponent of about 2, that is, the subjective speed grows to the approximate square of the physical speed (2).

One of the most popular ratio-scaling methods is "magnitude estimation" (14). With this method the subjects are presented stimuli of different intensities and are asked to assign numbers to them, depending upon how intensely

This was intended to make the scale easier to use because a certain value on the scale, e.g., 13, would match approximately a heart rate of 130 beats·min^{-1} for 30-50-year-old subjects. However, this close relationship was not intended to be taken too literally because the meaning of a certain heart rate value as an indicator of strain depends upon age, type of exercise, environment, anxiety, and other factors. The advantage of not having to refer to a table to interpret the meaning of a rating value has been great and has overshadowed the disadvantages of the scale.

With popular category scales the term "moderate" (or a similar expression) is placed in the middle of the scale, and the terms "strong" and "weak" with the addition of "rather" or "very" are placed symmetrically on each side of "moderate." This does not create an interval scale, for when comparing the responses, R_1, R_2, R_3. . .R_i. . .R_n, it cannot be said that the distance from R_1 to R_2 is equal to that from R_2 to R_3. Because the RPE scale is, on the other hand, constructed to increase linearly with the exercise intensity, it may be stated that R_4-R_3 = R_3-R_2, or when stated in RPE units, 17-15 = 13-11 as with equal right heart rate (in beats·min^{-1}) 170-150 = 130-110.

"Experiential Value" of Category Expressions

It is true from a simple mathematical point of view that a ratio scale is more accurate than an interval scale (with equal distances but without a true zero), which in turn is better than a rank-order scale. With a ratio scale all types of mathematical calculations can be performed and direct comparisons with physical and physiological measurements, obtained with true ratio scales, can be made. However, the meaning of a certain value is not only dependent upon where it belongs on a ratio scale, it is also given by the context in question. As an example, when I visited the United States for the first time in the 1960's, someone talked with me about a certain athlete who was 6 ft tall. This description did not mean much to me. I understood, of course, that he was taller than someone 5 ft tall and was shorter than someone 7 ft tall, but I did not know if he was considered to be "tall" or "short." Similarly, an American unaccustomed to the metric system will encounter the same problem when he is told that someone is 1.90 m tall. It will be understood that his height is 1.9 times greater than the true meter unit in Europe, but not whether the person is "tall" or "short." However, if it is also noted that the person is two standard deviations above the mean in the Swedish male population, new information is obtained permitting relative comparisons of individuals. Similarly, an "additional meaning" may also be obtained when using some category scales.

Despite the fact that these scale values do not have the good ratio properties, we may have the advantage of scale anchors in certain "population norms" or "experiential values." Category expressions like "comfortable intensity level" and "preferred radio volume" thus provide a good interindividual meaning. Category expressions denoting subjective intensities of heaviness in everyday experiences often refer to a special class of objects, such as suitcases, rackets, or glassware. If someone believes that plastic glasses are "very light," it may be interpreted that the perceived heaviness underlying the expression is a certain distance (which might be identified in relative z-scores) below the mean in his sample of experiences, which stands in a certain relation to another person's experiences and to a given population. If we exchange glasses with skis, the "absolute" subjective intensity will be much higher, but the relative position in each sample may be the same.

The Range Model

In a laboratory setting subjects are tested with more "meaningless" stimuli, that is, specific objects or classes of objects are not referred to as in the example above, the cognitive evaluation of the subjective intensity will depend to a much higher degree upon the "absolute" perceptual intensity and its position in the total spectrum, which ranges from an extremely weak intensity (e.g., R_1 is equal to the threshold [R_0] or somewhat above that) to an extremely strong intensity (e.g., R_n = R_t, i.e., a terminal [t] value equal to a maximal intensity or somewhat below that).

The verbal expressions used to report perceived exertion in treadmill running or ergometry cycling thus depend more on sensory signals than the cognitive frame of reference. The physical stress causes a certain strain for each individual depending upon his or her capacity relative to the position of the intensity in each individual's "absolute" range. This simple "range-model" indicates a fundamental principle for interprocess comparisons (1,2,4). It must be modified when comparing interindividual responses and when comparing responses from different situations. As a result, there may be some differences between an exercise intensity based on that perceived by the subjects and based on heart rate data depending upon the kind of exercise. The relation between RPE and heart rate may change somewhat from walking to running.

Use of Perceived Exertion in Exercise Prescriptions

Perceived exertion is often taken into account for exercise prescriptions. However, those skeptical about the valid application of perceived exertion often refer to the discrepancies found when comparing RPE values and heart rate data to illustrate difficulties encountered when it is used in clinical rehabilitation. For example, a patient training with a "target heart rate" of 130 beats·min^{-1}, which can be achieved by walking strenuously, may rate the exertion as "hard" with an RPE of 15; however, his heart rate may reach 150 beats·min^{-1} when running, but he may perceive the exertion to be the same. To those who object to the use of the RPE scale, it may be explained

they are perceived. The subjects are most often asked to match numbers to the perceived physical stimulus in such a way that the numbers vary directly in proportion to subjective intensities.

Power Functions

Most psychophysical relations may be described by power function, with exponents ranging from 0.3 to 3, depending mainly upon the modality tested but also depending on experimental conditions (9,15). The first studies of perceived exertion in heavy physical work were performed in the end of the 1950's by Borg and Dahlström (6,7) and in the 1960's by Borg (2). Even in this "modality," power functions described the perceptual variation with the physical intensity. The exponent was about 1.6, very close to that found for subjective force of handgrip, viz., 1.7 (12).

It has been possible in most psychophysical studies to prove that equal stimulus ratios produce equal response ratios (15). Thus, the Fechnerian log-function provides a fundamentally inaccurate description of the general stimulus-response function, which instead should be represented in the form of a power function. The most general form of this equation that fits both psychophysical and physiological functions was originally proposed by Borg (1):

$$R = a + c(S-b)^n,$$

where R is the intensity of the response, S is the stimulus intensity, a and b are constants showing the starting point of the function, c is the proportionality constant, and n is the exponent.

Difficulties in Interindividual Comparisons

One major drawback with ratio-scaling methods is that they do not provide any direct "levels" for interindividual comparisons. Good general functions for a group of subjects can be obtained, but it is difficult to compare the subjects with each other because subjects are asked only to make relative comparisons. One subject may rate a 1-pound weight a "10" and a 2-pound weight "25," while another may assign "4" and "10" to the same weights. However, the subject assigning the "25" rating to the 2-pound weight does not mean that he perceives it to be heavier than the subject who has rated it "10."

To overcome the difficulties associated with the ratio-scaling methods, a scale for ratings of perceived exertion was developed by Borg (2). The first was a 21-grade scale with verbal anchors similar to those used in a subsequent RPE scale. It represents one kind of category scale, often used in many applied situations when a simple but direct estimation of the subjective intensity is needed, but when the metric properties of the scale are of less importance. Some category scales may be interval scales, but most of them are rank-order scales. It may only be stated that one subjective intensity is more "intense" than another; however, neither the degree of intensity nor the position of zero intensity can be accurately determined. An advantage of a category scale is that it is possible for direct interindividual comparisons to arise because the subjects react to the stimuli in a more "absolute" way. Consequently, we can be rather certain that if the subject says a weight is "light," it will seem relatively lighter to that person than to someone who says it is "heavy."

Perceived Exertion—Heart Rates and Lactate Accumulation

High correlation coefficients between ratings of perceived exertion and heart rates indicate the differential value of the scale but not the general validity of the growth function. Because the perceived exertion determined by ratio-scaling methods grew with an exponent of about 1.6, it was concluded by Borg (2) that an integration of central factors, such as heart rates, and peripheral factors (such as blood lactates, with an exponent of about 2) would better "explain" the psychophysical variation than any single physiological variable.

Borg's RPE Scale

A new category scale for ratings of perceived exertion was constructed by Borg (3) to increase linearly with the exercise intensity for work on cycle ergometer. Because oxygen consumption and heart rate increase linearly with work load, this would be a convenient means of constructing a scale, even if it did violate the true growth of the perceived intensities. The RPE scale (Table 1) has become very popular and has been translated into many different languages, including French, German, Japanese, Hebrew, and Russian. In many studies, correlations of ratings and heart rates ranging from 0.80–0.90 have been found, but high correlations with other physiological variables (8,10) have also been found.

The scale values range from 6 to 20 and can be used to denote heart rates ranging from 60-200 beats·min^{-1}.

Table 1. The 15-grade scale for ratings of perceived exertion, the RPE Scale. (3)

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	

that the discrepancy is understood and may be taken into consideration when instructing the patient.

In defense of the use of perceived exertion it may be said that there is little evidence that a certain heart rate is a better indicator of "dangerous strain" than a certain perceived exertion. On any given day one may run and achieve a heart rate of 150 and feel "fine" with an RPE of 13, while on another day the same exertion may cause the runner to feel "bad" with an RPE of 17 as a result of physical and emotional negative factors.

The elevated RPE value may be used equally with heart rate in determining a "risk factor." Neither a single RPE value nor a heart rate measure may be used alone as an accurate indicator of "dangerous strain." They complement each other.

A "perfect" or "excellent" indicator of "dangerous strain" must involve an integration of all important risk factors, such as arrhythmias, blood pressure elevations, ST-depressions, body temperature changes, blood lactate levels, and hormonal excretions. A single heart rate must be used in relation to the other strain variables and understood to be just one factor in a complicated pattern of interacting factors. A patient's perceived exertion is considered in exercise prescription because it is related closely to the heart rate but it also integrates some other important strain variables.

A New Category Scale with Ratio Properties

In recent years we have tried to develop a category scale with ratio properties, that is, a simple category scale for differential use that has the positive attributes of a general-ratio scale. In developing such a scale we have referred to our previous studies of perceived exertion and the known relationship between the RPE scale and a ratio scale. We have also referred to studies of quantitative semantics, "range problems," and psychophysical relationships (5).

The main idea is that numbers should be anchored by verbal expressions that are simple and understandable by most people. The expressions should in turn be placed in the correct position on a ratio scale, where the expressions belong according to their quantitative meaning. If, for instance, we determine 4 to represent "light," 2 should represent half of that intensity. We then have to choose an expression with an inherent meaning of being about half as intense as "light," such as "very light."

To make the scale easy to use for the lay population and not restricted to those familiar with mathematical or technical terminology, we should use a simple number range, e.g., 0-10. We have chosen to denote 10 as "very, very strong" or "very, very heavy" for the heaviest exercise or physical work perceived by the subject, e.g., lifting weights or running. To be able to cover a reasonably good range of intensities, the opposite end of the scale, identified as a "very, very weak" intensity or a "very, very light" work, had to be set to 0.5. The different verbal expressions were then placed where they belonged according to their ratio properties. When using this scale, people are permitted to use decimals and also to go beyond 10 and 0.5. The scale is presented in Table 2.

Table 2. The new rating scale constructed as a category scale with ratio properties. (5)

0	Nothing at all	
0.5	Very, very weak	(just noticeable)
1	Very weak	
2	Weak	(light)
3	Moderate	
4	Somewhat strong	
5	Strong	(heavy)
6		
7	Very strong	
8		
9		
10	Very, very strong	(almost max)
•	Maximal	

Recent studies by Borg (5) of this new category scale with ratio properties have given psychophysical functions of about the same appearance as those obtained with magnitude estimation. Exponents of about 1.6 have thus been obtained for perceived exertion in cycle ergometer exercise. In another psychophysiological study (11) a close correlation between ratings according to this new scale and both blood lactate and muscle lactate levels were obtained.

When to Use a Certain Scale

There may not be one perfect scale for all kinds of subjective intensities in all kinds of situations. Perhaps we should use different scales depending upon the purpose of the study. At present I think, however, that the old RPE scale is the best one for most simple applied studies of perceived exertion, for exercise testing, and for predictions and prescriptions of exercise intensities in sports and medical rehabilitation. The new category scale with ratio properties may be especially suitable for determining other subjective symptoms, such as breathing difficulties, aches, and pain.

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