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Twelve meanings of the measure constant in psychophysical power functions

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The measure constant in the psychophysical power equation can have at least 12 distinct referents. These depend upon standardized (SI) units of measurement of the physical stimulus, psychophysical method, group and individual differences in judgment, modality- or quality-specific differences, special sensory/perceptual characteristics, characteristics of central/peripheral processing, pathological differences in sensory/perceptual reaction, and differences in the transformation of distal to proximal stimuli.

Interest in characteristics of the psychophysical power law has centered largely on the values of the exponent (S. S. Stevens, 1957, 1975). The purpose of this paper is to help redress the imbalance by considering the several meanings of the measure constant. In the general equation, which applies both to perceptual and physiological variables, $R = a + c(S - b)^n$, the measure constant is the value of c relating sensation or physiological magnitude R to stimulus intensity S. The constants a and b determine the starting point of the function or the absolute threshold R_0 and S_0 (Borg, 1961, 1962; Mountcastle, Poggio, & Werner, 1963).

In fact, the assessment from any set of data of the measure constant c will depend on the assessed values of the exponent n and the constants a and b. This is partly a straightforward, empirical matter of parameter estimation. The constant b provides little problem when its value is small; in some modalities, however, it can be large relative to the range of S. The constant a can also be large; moreover, it can vary widely over individuals and yet at the same time be difficult to measure with precision. The exact assessed values of a and b interact with the assessed values of the other constants, n and c. We point out these interactions here, for in the remainder of the paper, we will consider only the measure constant c without regard to the other constants of the power equation.

Often, the measure constant's significance is dismissed by saying that the constant merely depends on the units by which stimulus and response are measured. This is true only in part. In magnitude estimation, for example, the value of c will, for a given set of stimuli, depend somewhat arbitrarily on the numerical modulus that the subject(s) chooses or that the experimenter assigns to the first stimulus. Nevertheless, the measure constant can in fact have several meanings, and frequently, the constant can be important for specifying the sensitivity of an individual or group of individuals. Thus, the meaning of this constant depends on the stimulus scale and the psychophysical method chosen, on the physical properties/parameters of the stimuli used, on individual cognitive-response differences, and on true individual sensory differences in the "capacity for distal S production" (e.g., differences in physical strength).

The value of the constant is established by the following major factors, which yield a dozen different assignments: (1) the physical scale chosen, (2) the psychophysical method, (3) individual judgmental differences, (4) modality- or quality-specific differences, (5) special sensory/perceptual characteristics, (6) characteristics of central/peripheral processing, (7) pathological differences in sensory/perceptual reaction, and (8) differences in the transformation of distal to proximal stimuli.

To account for the different meanings of the measure constant, we may divide it into a series of subconstants and write (ignoring the additive constants): $R = c_1 \times c_2 \times c_3 \times c_4 \times c_5 \times c_6 \times c_7 \times c_8 \times c_9 \times c_{10} \times c_{11} \times c_{12} \times S^n$.

THE PHYSICAL SCALE

The first constant, c_1, may be chosen to depend upon the physical scale in a certain reference experiment ("standard"). The value of c_1 defines the S scale in SI units. For example, in an experiment on subjective force of handgrip in healthy male college students, using

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ratio estimation or fractionation with a "maximal" or "terminal" (t) sensation R_t set to "100," and so forth, the scale in newton (N) determines the value of the constant.

The second "scale constant," c_2, will be needed if some other S scale has been used. One may have used an old, non-SI scale, such as kilopond for force, or an energy scale with the threshold, S_0, as the unit. Thus, $c_2 = 1$ for the SI scale, and c_2 = (non-SI unit/SI unit)^n for the non-SI scale. For example, if for handgrip $R = 1.0 \times S^{1.7}$, S in newton, then $R = 1.0 \times (kp/N)^{1.7} \times S^{1.7}$, S in kilopond.

THE PSYCHOPHYSICAL METHOD

The methodological constant, c_3, is either set by the experimenter or determined by the subjects' numerical judgments. An example of the former occurs when the method is ratio estimation (RE): The experimenter decides what number R to assign to, say, the greatest S value, using the ratio estimates to determine the other, lower values of R. When the method is magnitude estimation (ME), it is typically the subjects' responses that determine c_3. If ratio estimation is used in a "standard experiment," the constant c_3 may be set to 1. In an experiment with both ratio estimation and some other method (Mx), $c_3 = R_{t(Mx)}/R_{t(RE)}$; for example, if Mx is magnitude estimation and the highest S value in the experiment is given R_t = "100" in ratio estimation and "40" in magnitude estimation, then $c_3 = .4$.

INDIVIDUAL JUDGMENTAL DIFFERENCES

The choices of method, scale, and modality in the standard experiment give a certain value to the measure constant. This value must, however, be corrected depending upon what group of subjects is tested. Cognitive-judgmental differences between various populations should be taken into account and reflected in the constant c_4. Beyond this, there are the individual differences in judgment, these deviations from population means being reflected in c_5.

MODALITY- OR QUALITY-SPECIFIC DIFFERENCES

Perceptual intensities may vary among modalities at "maximal" sensory stimulation; or, within a single modality, stimulus intensities for different qualities may need energy scales with the absolute threshold as the unit in order to equate them perceptually. There is, therefore, a need to correct the stimulus with a modality-specific "sensitivity" constant that is distinctive for each quality. The following is a good example: The auditory system is not equally sensitive to all sound frequencies, largely because energy at different frequencies is attenuated or amplified differently as the sound is transmitted through the ear canal and ossicles to the basilar membrane (see Marks, 1977; Zwislocki, 1965). To account for the fact that, say, at 10,000 Hz a sound must have 10 times the energy as one at 1,000 Hz in order to be equally loud, a sensitivity factor, c_6, specific to each sound frequency, must modify the stimulus, $R = c_6 \times S^n = (c_6{}^{1/n} \times S)^n$. Because the "sensitivity" factors across quality can vary substantially among people, we need to account for individual differences in c_7.

SPECIAL SENSORY/PERCEPTUAL CHARACTERISTICS

We use this heading to indicate the necessity from a philosophical perspective of including a constant that may serve to differentiate individuals in their (mainly) central sensory/perceptual characteristics. The responses of individuals chosen for the reference experiment with the standard procedure should reflect some "ideal" psychophysical relation that is equally valid for everyone. However, this is unlikely. Some people may, for instance, have more intense perceptions than others. If we could make direct absolute comparisons across individuals (which, at present, we cannot), we could evaluate the constant c_8, which denotes these deviations. In the absence of empirical methods to measure absolute perceptual intensities, we set $c_8 = 1$.

CHARACTERISTICS OF CENTRAL/PERIPHERAL PROCESSING

The values of c_9 and c_{10} represent the effects of stimulus parameters influencing sensory/perceptual processing, specifically, parameters that cause proportional changes in sensation. For example, the loudness of a pure tone heard with two ears is usually twice that of the same level heard with one ear (Marks, 1979). Thus, for the population as a whole, the binaural $c_9 = 2 \times$ monaural c_9. Individuals may differ, however, in their degree of summation, as characterized by c_{10}. Thus, for an individual, $c_{9_{bin}} = 2 \times c_{10} \times c_{9_{mon}}$. A similar effect is obtained in perception of effort or exertion, depending upon how large are the muscle groups involved, or whether the individual is lifting weights with one hand or two, or whether he or she is biking with two legs or only one.

PATHOLOGICAL DIFFERENCES IN SENSORY/PERCEPTUAL REACTIONS

After correcting for cognitive-judgmental differences (e.g., by complementary tests of the judgmental process, perhaps by a battery of tests evaluating judgments in several modalities), there will in certain cases remain variations due to pathological functioning of the sensory system. The magnitude of this factor is denoted by c_{11}. Sometimes it may be estimated from threshold determination, and otherwise, by cross-modality matching (J. C. Stevens & Marks, 1980; S. S. Stevens, 1975).

DIFFERENCES IN THE TRANSFORMATION OF DISTAL TO PROXIMAL STIMULI

This constant, c_{12}, reflects individual (or group) differences in the transformation of distal stimuli to proximal ones. A good example appears in experiments on perceived exertion, in which individual differences in strength (differences in the "terminal" value of S that the subject can produce, S_t) require that the stimulus for every subject be denoted in terms of his or her S_t: $R = c_{12} \times S^n = (c_{12}{}^{1/n} \times S)^n$. The constant $c_{12} = R_t/S_t^n$. With R_t equal for everyone (Borg, 1961, 1962), individual estimates of c_{12} can easily be obtained.

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