that increased precision in one type of psychophysical judgment is accompanied by decreased precision in another, but that both types of judgment cannot be experienced at the same time? Is it possible that human perception does not exist as a phenomenon except as a complex interaction between experimental conditions, physical and psychological measuring instruments? I am becoming more convinced that the psychological instrument changes according to the particulars of the physical conditions being assessed (cf. Wheeler & Zurek 1983).

To resolve Fechner versus Stevens: Settle the dispute concerning "ratios" and "differences"

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Krueger's theory gives a concise account of category ratings, magnitude estimations, and summated jnds by finding a compromise between the psychophysical functions of Fechner and Stevens. To negotiate this compromise, Krueger asks each side to give up a cherished assumption. However, there is a theoretical distinction between the approaches of Fechner and Stevens that would allow their modern-day advocates to continue to dispute Krueger's theory, even if all of the empirical issues involving ratings, estimations, neurelectric functions, and Weber's law were settled. To resolve this debate, it is necessary to bring other data to bear so that we can understand the processes by which stimuli are compared, combined, and judged in context.

The dispute between Stevens and Fechner can be viewed as one about whether subjects use a ratio operation and/or a subtractive operation to compare stimuli. Because the same data can be interpreted as consistent with either a logarithmic or a power function, depending on whether equally discriminable stimuli are assumed to be separated by equal distances or by equal ratios (Torgerson 1961), the choice of psychophysical function depends on the assumed operation. One approach to placing new constraints on the comparison processes is to investigate the operations subjects use when instructed to judge "ratios" and "differences" (Birnbaum & Veit 1974a; Elmasian & Birnbaum 1984). Quotation marks are used to distinguish instructions to the subject or judgments of the subject as opposed to actual or theoretical operations, because "ratio" judgments, for example, may not fit the ratio model.

Such research has led to the subtractive theory of stimulus comparison (Birnbaum 1978; 1980; 1982). Birnbaum theorized that subjective values for most continua are inherently interval scales, for which differences and ratios of differences are meaningful, but simple ratios are not. According to the theory, when instructed to judge either "ratios" or "differences," subjects compare the same values by subtraction in both cases but use different numbers in responding, depending on the contexts created by the tasks. When instructed to judge "ratios of differences" or "differences of differences," subjects use these operations as instructed, because they are well defined on interval scales. This theory has several points of agreement and disagreement with the theory of Krueger.

Krueger's theory and Birnbaum's agree on the assumption that subjective magnitudes are independent of the method used to measure them, that category ratings are roughly a linear function of subjective magnitude and that magnitude estimations are a positively accelerated function of subjective value. The theories disagree about the viability of the power function for approximating the psychophysical (input) and judgment (output) functions. On these points, Krueger's theory agrees with that of Rule and Curtis (1982), which also represents input and output functions as power functions and treats the output function for magnitude estimation as the inverse of the psychophysical function for number. In contrast, Birnbaum (1978; 1980; 1982) considers the output function for magnitude estimation to be a judgment function that can take on many forms, including the exponential.

The theoretical concept of a judgment function offers a better representation of magnitude estimations than the theory that magnitude estimations can be corrected by the inverse of the psychophysical function for number. The judgment function is useful for connecting ratings, "ratio" estimations, and other responses with one coherent theory, whereas the number notion needs to explain why a 1–100 rating scale does not involve numbers. The judgment function explains why numerical responses given in rating or magnitude tasks can be so easily manipulated by variations of the stimulus and response distributions, whereas the psychophysics of number theory does not easily accommodate contextual effects (Birnbaum 1980; Mellers & Birnbaum 1982; Mellers et al. 1984).

The sensitivity of the judgment function to changes in the response examples also helps to explain how the judgment function can be exponential for magnitude estimation. When the examples are geometrically spaced – for example, "one-fourth," "one-half," "one," "two," and "four" – then the judgment function will be exponential if the subjects treat these responses as equally spaced categories. The judgment function accounts for the exponential relationship usually observed between "ratio" estimations and "difference" ratings. An exponential judgment function explains why "ratio" judgments fit the ratio model, even though subjects are actually computing subjective differences; it also explains why reverse attributes, such as "ratios" of easterliness and westerliness, are reciprocally related (Birnbaum 1980; 1982).

A recent study of the prestige of occupations by Hardin and Birnbaum (in press) illustrates the difficulties faced by the number theory of magnitude estimations. When the instructions mentioned a "ratio" of 64 times, the modal and median subject reported that the occupation of *physician* is 64 times as prestigious as the occupation of *trash collector*. However, when the largest "ratio" mentioned in the instructions was 4, then this same pair received a judgment of only 4 times. Such malleability is consistent with the judgment function of subtractive theory, because in that theory, "ratio" judgments are category ratings of subjective differences in which the experimenter has chosen a set of geometrically spaced numbers for the subject to use as categories, thereby inducing an exponential transformation.

Although contextual effects are acknowledged, Krueger's theory assumes that magnitude estimations can be corrected for the use of numbers by taking the square root. However, it is difficult to see why taking the square root of 64 or 4 solves the problem that magnitude estimations can differ drastically as a function of incidental manipulations of the numerical examples used in the instructions. Previous consistency in "correcting" magnitude estimations may be due to the fact that experimenters have found examples to use in defining their scales that made the theory seem to work. Judgment theory explains why it is possible to make the psychophysics of number theory look either good or bad, since it predicts that manipulation of the examples should produce different judgment functions in a lawful fashion.

Krueger concedes a willingness to revise the power function for the psychophysical law. It is worth mentioning that in some cases, judgments of "ratios" are not compatible with the power function and the ratio model simultaneously. According to the ratio model, and the power function of physical value, judged "ratios" should have the same rank order as physical ratios. However, this implication of the power function has been systematically violated in studies of loudness (Birnbaum & Elmasian 1977) and the heaviness of lifted weights (Mellers et al. 1984). Instead, judgments of both "ratios" and "differences" become more extreme as a constant physical ratio is moved up the scale. This variance of "difference" judgments of constant physical ratios would also violate Fechner's law, assuming a subtractive model of comparison.

To give a complete account of psychophysics, a theory should not only accommodate single stimulus judgments; it should also explain the results of experiments in which the operations of comparison and combination can be tested. Theories of comparison permit a decomposition of the judgment function from the subjective scales, indicating that principles of the judgment function that apply to single stimuli also apply to judgments of stimulus comparisons. For example, Rose and Birnbaum (1975) found that "ratios" and "differences" of numbers could be fit by assuming that subjects compare stimuli by subtraction, using scale values that agree with the context-free scale derived from range-frequency theory applied to category ratings of single stimuli presented in different frequency distributions. Such experiments, which allow a separation of psychophysical and judgmental processes, impose greater constraints on the theoretical possibilities but do not as yet appear to require new scales of subjective value.

About assumptions and exponents

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Krueger seems to have convinced himself that despite more than a century of controversy about the matter, he has at last discovered the true relationship between physical stimulus and subjective magnitude. I am reminded at once of the sentiment of philosopher Karl Popper (1959) that

> a subjective experience can never justify a scientific statement. . . . Thus I can be utterly convinced of the truth of a statement; certain of the evidence of my perceptions; overwhelmed by the experience: every doubt may seem to me absurd. But does this afford the slightest reason for science to accept my statement? Can any statement be justified by the fact that K.R.P. is utterly convinced of its truth? The answer is, "No"; and any other answer would be incompatible with the idea of scientific objectivity. (p. 46)

There are, inevitably, unproved and probably unprovable assumptions in Krueger's argument. First, there is the crucial question of whether subjective measurement is even possible. In a recent chapter on psychophysics (Boynton 1984), I discussed this problem in a section on "Viewpoints concerning subjective measurement" (pp. 338–43). I offer several examples of the differences between "measurement" as physicists understand it and the "measurement" of sensation, and refer to the work of a famous committee appointed in 1925 by the British Association for the Advancement of Science "to consider and report upon the possibility of quantitative estimates of sensory events" (which ended as a hung jury: Ferguson et al. 1940). I also stress the fundamental problem of subjective measurement of sensory intensity, which is the lack of an unequivocal operation of addition corresponding, for example, to the laying of meter sticks end to end to determine a distance. In my view, one can conclude only that there exists a spectrum of opinion concerning the possibility of sensory measurement, ranging from liberal to conservative, not unlike the wide range of strong opinions related to political matters. In both cases, because what one feels depends on one's personal needs, subjective experiences, and biased assumptions, arguments cease to be scientific ones.

For his part, Krueger *assumes* "that different subjective rating methods tap, with varying accuracy or fidelity, the same basic underlying scale"; and although he cites Marks (1974a) for a contrary view, he does not discuss it. Krueger *assumes* that Stevens's "direct methods of psychophysical measurement" provide the "primary evidence" concerning the empirical relation between stimulus and sensation. In dealing with the problem of using number scales to rate sensory impressions, he *assumes* that the number dimension is used only once in making a response and therefore that "it should have the same effect regardless of whether the subject is judging a single stimulus or the difference between two stimuli." In each instance, Krueger states explicitly that the positions he takes are based on *assumptions*. And so, despite some convincing arguments and a scholarly discussion of a very large number of references, Krueger has not succeeded in laying the matter of subjective scaling to rest any more than the others who have labored unsuccessfully in this attempt over so many years.

I also wish to comment on a technical point. The equation (sect. 1, para. 3)

$$S = (S_{max}I^b)/(I^b + \sigma^b)$$

is not the Michaelis–Menten (a.k.a. Naka–Rushton) equation unless the exponent b is unity. Also, unless $b = 1$, the function does not vary from linear to logarithmic as I increases, but instead is nonlinear over its entire extent. This is because, at very small values of I, where σ^b dominates the denominator, the function approaches a power function $S = S_{max}I^b/\sigma^b$, and a power function is linear only if $b = 1$. I am perhaps a bit sensitive about this because it seems to be a little-known fact that David Whitten and I were the ones who originally suggested the need for an exponent of less than one for I in the Naka–Rushton equation (Boynton & Whitten 1970).

Unifying psychophysics: And what if things are not so simple?

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Krueger holds that "a unified psychophysical law is proposed in which each jnd has the same subjective magnitude for a given modality or condition, subjective magnitude increases as approximately a power function of physical magnitude with the exponent ranging from near 0 to 1 . . . and subjective magnitude depends primarily on peripheral sensory processes." In this commentary, we will confine ourselves to visual perception and investigate what happens if just one factor of the stimulus constellation – background luminance – is altered, and what this can tell us about the unified psychophysical law proposed by Krueger. Background luminance is important for Krueger's theorizing because all brightness studies on which he relies presented small visual stimuli against a uniform background.

First, it is surprising that Weber's law still needs to be refuted in a 1989 review article, and that this has to be done on the basis of deviations at the very low end of the brightness continuum (Holway & Pratt 1936; Woodworth 1938). (Note that the situation may be different for audition; Jesteadt et al. 1977.)

As early as 1916, Cobb noted that the Weber fraction is smallest when stimulus and surround have about the same intensity and that it increases as the difference between stimulus and surround grows (though more so when the stimulus is darker than the background). These results were confirmed later by Heinemann (1961) and Brysbaert and d'Ydewalle (in press; see Figure 1). The data in Figure 1 are difference limens obtained with the up-and-down transformed response rule (Wetherill & Levitt 1965) using two stimuli with a diameter of 8.2 degrees against a background of 41 × 20.5 degrees. Stimuli were separated by 8.2 degrees. If the data are plotted as Weber fractions against the difference between the stimulus and the background, a positive relationship is obtained with a steeper