

**STEVENS'
HANDBOOK OF
EXPERIMENTAL
PSYCHOLOGY**

Second Edition

VOLUME 1
Perception and Motivation

STEVENS' HANDBOOK OF EXPERIMENTAL PSYCHOLOGY

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VOLUME 1: Perception and Motivation

Edited by

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PREFACE

Stanley Smith Stevens' original *Handbook of Experimental Psychology*, published in 1951, comprised 36 chapters in six sections, all in one large volume. Here, the number of chapters has shrunk to 27, the sections to four, and the whole made more manageable as two volumes. The shrinkage is not in experimental psychology, for what has vanished are mainly importations into psychology from other disciplines. The original *Handbook* had chapters on the neuron, on synapses, on neural maturation, on the mathematics of growth curves, and on the anatomy of motor systems. Also missing are topics that now seem less pertinent to experimental psychology than they did right after World War II, such as engineering psychology, equipment design, and manpower training. As experimental psychology developed, it grew less dependent on other sciences and focused more sharply on its own territory.

Experimental psychology has grown differentially. What was a single chapter on Cognitive Processes has become a section of nine chapters in the present edition, a full third of the entire undertaking. The section on Sensory Processes has been transformed into Perception, a shift away from the physical and physiological to the more purely psychological. Physics and physiology remain, as they must, but the hope is that they make more meaningful contact with psychology's variables. The section on Motivation has grown from three chapters to five, almost all of the growth owing to the enriching convergence of behavioral biology and experimental psychology. The section on Learning and Adjustment changed its name to Learning and ceded Cognitive Processes and Speech and Language to other sections. It abandoned a mixture of substantive and methodological chapter topics that has become unwieldy, and it now presents four fundamental issues of simple learning: conditioning processes, stimulus discrimination, response strength, and the physiology of learning and memory.

This work is not so much a revision of Stevens' *Handbook* as it is a tribute to its editor. Although the present editors had quite different relations with our predecessor, all of us were significantly influenced by him in our work, and we are unified in our admiration for him as a scientist, scholar, and person. It is difficult to say anything about Smitty without saying a great deal. Here space permits us only to point to his distinguished contributions to sensory psychology and measurement, and to his Harvard presence for four decades, where in his highly individual manner he molded generations of experimental psychologists. So, too, did his *Handbook* shape experimental psychology in its time. Readers who are not familiar with him and his work may wish to consult his fascinating autobiography, which says much of interest about him and about our science (S. S. Stevens, *Autobiography*. In G. Lindzey (ed.), *A History of Psychology in Autobiography*, Vol. VI. New York: Appleton-Century-Crofts, 1974, pp 395–420).

Conversations among the editors about a possible new edition of Stevens' *Handbook* began in the fall of 1977. The old edition was out of date and out of print, but the question was whether a new one of so comprehensive a scope would be useful at a time when fine handbooks in perception, learning, and other specialized areas of experimental psychology have become available. Or were the fissures within experimental psychology so deep, we wondered, that it was pointless to try to span them in a single work. We came to believe that the very fractionation of our subject that

almost deterred us could be blamed in part on the lack of a contemporary *Handbook*. Experimental psychology has more coherence than is reflected in the specialized textbooks, handbooks, journals, and monographs of our time, or so we thought. Wiley, publisher of the original *Handbook*, agreed. The next step was to try to discover whether colleagues elsewhere agreed as well.

In the summer of 1978, a tentative outline, drafted by the editors, was sent to several dozen psychologists and other scholars. They were asked for advice on the idea of a new edition, on our outline, and on possible authors. Their answers helped mold our tentative plan into the present *Handbook*. Because of their generous response to our inquiry, the outline was extensively revised, a list of prospective authors drawn up, and, most significantly, the editors felt encouraged to proceed with the project. We acknowledge, but cannot fully repay, our debt to these consultants by listing their names.

Authors were recruited to write chapters of a level of scholarship sufficient to serve the needs of scholars and a level of clarity to serve those of beginning graduate students in experimental psychology. That was Stevens' conception of his *Handbook*, as it is the present editors'. All who were asked accepted or provided advice, about the outline of the *Handbook* or about alternative authors. Soon we had the assemblage here represented. Only the enduring and versatile George A. Miller turns up as author in both editions, although several others of the original authors helped as consultants.

Also enduring is Geraldine Stone Stevens, whom Stevens gratefully acknowledged in his Preface. We are grateful to her, too, for allowing us to grace this edition with "Stevens" in its title, for advice about how to put a handbook together, for editing about one-third of the chapters, and for her enthusiasm and encouragement.

The editors needed further help as the chapters came in. The reviewers listed below provided expertise where the editors' expertise fell short. Their criticisms and suggestions were often detailed, and occasionally fundamental. We know we speak not just for ourselves but also for the authors when we express most earnest thanks to these reviewers for accepting the largely thankless task of careful editorial reading and commenting. Much, though not all, of this edition's long delay from conception to publication is accounted for by the slow pace of the successive exchanges from reviewer to author and back again, always via an editor.

But the delay would have been worse, perhaps infinite, had it not been for the efforts of Susan Herrnstein, of whom we write, as Stevens wrote of Geraldine Stone Stevens in his Preface, that "she did more work on this handbook than anyone else." Detecting a vacuum, Susan Herrnstein took administrative command—organizing, advising, and keeping the communication and paper flowing among editors, authors, publisher, and, at last, printer. Despite a schedule already too busy, she found the time and energy to do the work that needed to be done when the rest of us did not. We cannot begin to repay our debt to her, but our profound gratitude we can at least acknowledge here.

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MEASUREMENT, SCALING, AND PSYCHOPHYSICS

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INTRODUCTION

To most physical scientists, the term *measurement* brings to mind issues of precision, reliability, bias, and technique. One takes for granted that the attribute in question—be it the velocity of light, the mass of an electron, or the diameter of the sun—is measurable, that it can be quantified in a consistent and meaningful way. In the physical sciences very precise systems of measurement have been developed that permit largely observer-free descriptions of physical objects and events. But think back to the early history of physics, when the very nature of many measures was a matter of doubt and debate, and most measurement systems in use resulted from the needs of trade and commerce, not physical theory. True, there were strong intuitive notions of what we now call force, weight, mass, time, velocity, momentum, work, heat, and temperature, but it took a great deal of effort to develop methods for measuring these attributes of physical systems and to understand the relations among them. In the process, it became necessary to introduce some far less intuitive but equally important measures, such as entropy,

kinetic and potential energy, acceleration, impedance, and charge.

Psychological measurement is in a comparable, floundering state with informal concepts that seem to admit of degree or amount, but whose means of measurement remain crude, controversial, and uncertain. Subjectively, our sensations of hunger, loudness, and sweetness are no less real than our sensations of force, energy, and acceleration. Moreover, for both psychological and physical attributes, our sensations suggest a measurement system that codes the degree or amount of the attribute or property in question. However, it is important to recognize an essential difference between the objectives of physical and psychological measurement. Physics studies certain properties of space, matter, and radiation, not the sensations they engender, although there is no doubt that in its early development physics was strongly guided, and sometimes misguided, by these sensations. In psychology, we are concerned with the sensations themselves, and this difference poses a challenge to develop measures that are appropriate for our special purposes. The system of measurement that develops in

psychology will undoubtedly turn out to resemble that of physics in certain fundamental ways, but new problems requiring novel solutions are also likely to emerge.

Physics and its applications exhibit three distinct levels of theory. First, there are the primitive relations among attributes that determine both the measurement representations and the interconnections among measures, as reflected in the structure of physical units. Second, there are the various laws of physics that are expressed entirely in terms of these measures, such as the basic equations of electromagnetic theory (Maxwell's equations), of hydrodynamics, of kinetics, and of statistical mechanics. And third, certain particular systems are modeled and the equations are solved for those cases. An example is the force exerted on a particular airfoil in a particular fluid flow, or the movement of the needle of a voltmeter when placed across a particular circuit under particular conditions. Keep in mind that, at each of the three levels, important regularities are found, all of which are called laws; those of measurement, those of general physical processes, and those of particular physical systems. Although they all express regularities, they are obviously not all of the same type, since they differ in generality.

If three distinct levels really can be distinguished, at which level does the psychophysicist operate when studying loudness? If a scale of loudness is developed, is it (1) an example of measurement, (2) a part of some psychophysical theory, or (3) the manifestation of the operation of a mechanism? In the first case, it must eventually be shown to arise as the representation of a lawful qualitative structure. In the second, it is best thought of as a construct whose ultimate status is not necessarily clear; often constructs of theories eventually become basic measures, once the situation is better understood. And in the third, it may best be thought of as a random variable, reflecting the probabilistic character of a mechanism, but not necessarily having anything to do with fundamental measurement.

We discuss the first separately and then lump the other two.

The Strategy of Measurement and Scaling in Psychophysics

In following this strategy we suppose that the

sensations themselves are attributes of the organism, comparable in many ways to the properties of physical objects. As such, these attributes are assumed to be highly stable and regular, and thus they can be subjected to careful analytical study and represented numerically in a manner analogous to physical measurement. This approach is concerned not only with the assignment of numerical values to the psychological states, but also with the way in which the observed psychological measures possess various formal properties of the number system into which they are being mapped. For the purpose of this chapter, we will refer to this as the measurement approach.

If this approach is followed and succeeds, one anticipates the discovery of general laws relating the sensations to physical attributes. That is, the measured sensations are expected to correspond systematically to the physical quantities that give rise to them. This is the point of view, more or less explicit, that has informed the tradition of psychophysical measurement that began with Fechner (1860) and received major impetus in this century by Thurstone (1927), Stevens (1951, 1975; see the latter for numerous references), and many others. For example, sound intensity, that is, the amplitude of the pressure wave impinging on the eardrum, is a well-understood physical attribute that is highly correlated with the sensation called loudness. It is, however, by no means identical to it. For one thing, the relationship is not linear; twice the amplitude does not give rise to twice the perceived loudness. Moreover loudness is affected by the frequency of the sound as well as by its intensity. A more striking example, perhaps, is color vision. Light stimuli are described at the physical level by the energy at each of an infinity of wavelengths, but perceptually this infinite-dimensional space is mapped onto the much simpler, three-dimensional structure of the psychological color space. Thus, the relation between the physical stimulus and the corresponding psychological response may be quite complex, although this approach assumes that the relation is lawful.

For the measurement view to prevail in psychophysics or, more generally, in psychology, or even more generally, in biology, it appears necessary for some structure of interconnected scales to arise, much as exists in physics. This would mean a complex pattern of

reductions of some psychological scales to others, with a resulting simple pattern of units, and quite possibly some simple connection with the scales of physics. This appears to be the program that Stevens was pursuing; we discuss it below. To anticipate, Stevens attempted to argue that the psychological scales of intensity are all power functions of the primary physical scales that manipulate each attribute. Moreover he attempted to show that a consistent pattern of power functions holds among the scales of intensity, suggesting a single underlying attribute of psychological intensity. Were that true, then psychophysical measurement would simply enlarge the system of physical measures, just as electromagnetic theory did in the second half of the last century, and one could anticipate the development of psychological theories involving these sensory (and perhaps other) variables on the model established in physics.

Within this tradition of measurement there are a number of subschools and points of view. Perhaps most notable is the division between axiomatizers and scalars. The axiomatizers (whose approach is exemplified in Krantz, Luce, Suppes & Tversky, 1971, Narens, 1985, and Roberts, 1979) tend to treat the following type of problem: If a body of (potential) qualitative observations satisfies certain primitive laws—axioms that capture properties of these observations—then is it possible to find a numerical structure that accurately summarizes these observations? In technical terms, the question is: To which numerical structures is the set of qualitative observations isomorphic? An isomorphism is a one-to-one mapping between structures under which the structure of the one maps into that of the other. It is also desirable to have an explicit process whereby the numerical structure can be constructed from the qualitative one. This literature, which is a part of 'applicable mathematics,' is purely mathematical in character, but the choice of structures to be studied is greatly influenced by the type of application intended. The objective of this approach is to illuminate the range of possible situations that permit the development of a measurement system, to determine the type of system that is appropriate, and to provide at least one method for its construction.

The scalars pose a different, often more immediately useful, problem. They are concerned with transforming psychological data, which

are for the most part fallible in the sense of exhibiting a certain amount of inconsistency and irregularity, into some familiar numerical representation. For example, the question may be how best to locate points in some geometrical, often metric, space so as to represent the psychological relationships among stimuli? This approach accepts the fallible nature of the data, and is, therefore, not so much concerned with verifying that the data satisfy specific properties entailed by the chosen representation as with searching for the best possible fit of the data within the chosen class of representations. The fit between the original data and the solution is evaluated in some global, statistical sense.

In the short run, this scaling approach has proved to be very directly usable. In the long run, solving some of the deeper questions posed by the axiomatic approach to measurement, such as defining the possibilities for measurement, discovering how complexes of structures interrelate (as, for example, those underlying the system of physical units), and determining what kinds of statements are meaningful in a measurement structure, may have more profound implications for progress in psychology.

The Strategy of Mechanisms in Psychophysics

The second major strategy for describing psychophysical attributes is to focus on sensory and other mechanisms in the organism. This strategy is directed at analyzing the internal systems responsible for the transduction, transformation, storage, and interpretation of sensory information. In this view, the organism is likened to an information processing machine, with the sensations corresponding to certain aspects of its internal workings, perhaps the firing patterns of various key neurons that are monitored by an executive control system. This was probably the implicit view of most psychophysicists working on sensations in the 19th century, including the remarkable Helmholtz (1867). It is certainly the dominant point of view of psychophysicists working in this century. Consequently, we will call this the psychophysical approach, and the last part of the chapter will be devoted to a summary of some classical and contemporary work in this field. In that section, a distinction is made between local