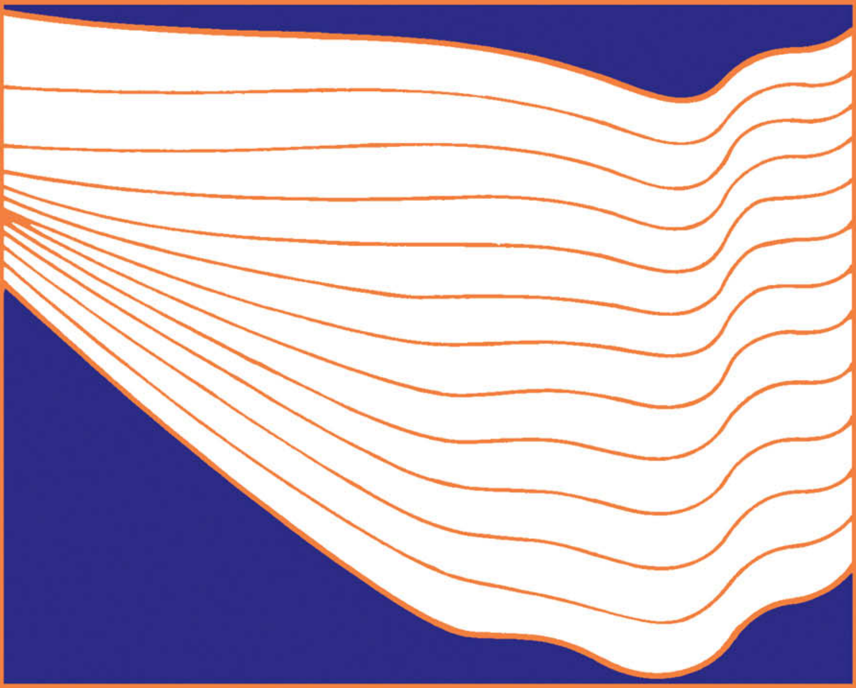
Sensory Processes

The New Psychophysics

LAWRENCE E. MARKS



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LAWRENCE E. MARKS

John B. Pierce Foundation Laboratory
and Department of Psychology
Yale University
New Haven, Connecticut

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CONTENTS

PREFACE

In books on sensory psychology it is not uncommon to find prefaces that begin by pointing out the unique role that the senses play in human behavior and the acquisition of knowledge: To wit, the senses are portals to the mind, the senses detect and organize information about the world, and so on. In fact, such introductory remarks are so frequent that I shall dispense with them.

Psychology, philosophy, and physiology all converge on the study of the senses. Of these the psychological approaches—phenomenological and psychophysical—are propaedeutic. First comes the phenomenological examination of sensory experience, of the attributes and qualities of sensory perceptions. This leads almost naturally to the psychophysical examination of sensory experience: How do the perceptual attributes of sensations relate to the physical stimuli that produce them?

The psychophysics of human sensory processes has made startling advances over the past two decades. In large measure, these advances are the outcome of application of direct scaling procedures—what the major exponent, S. S. Stevens, has called "the new psychophysics"—to the study of sensation. Through the treatment of the intensities of sensations as measurable quantities, capable of direct assessment on the part of human subjects, sensory psychologists have been able not only to evaluate sensory magnitudes, but perhaps more importantly, to utilize such evaluations in order to elucidate the nature of fundamental sensory processes.

This book summarizes, describes, and theorizes on the application of the new psychophysics to the study of sensory processes. Its aim is to deal with substantive issues in sensory psychology, primarily by treating sensory dimensions and attributes as measurable quantities. A particular goal is to integrate results obtained via procedures that employ direct scaling with results obtained via older, more traditional procedures such as intrasensory matching. The emphasis, however, is clearly on the new psychophysics.

Like most books on sensory psychology, the present volume does deal extensively with visual and auditory processes, but the psychophysics of olfaction, taste, and the skin senses is far from neglected. I attempted in particular to emphasize studies of these three "lower senses," in large part because these sense departments have benefited proportionately the most from the new psychophysics. Many of the recent advances in knowledge and understanding of olfactory, gustatory, and somesthetic processes derive from application of direct scaling procedures.

Sensory Processes will be found useful by researchers and graduate students in sensory psychology, but will also be useful as a reference text for advanced undergraduate students interested in the senses. Its core consists of four central chapters that deal with the ways that stimulus variables—intensity, composition, duration, spatial distribution—influence and determine the magnitudes and qualities of our sensations. Since the approach taken is topical, that is, it deals with topics such as temporal summation and spatial inhibition, it was possible to point out, when applicable, those principles of sensory functioning that pertain to several senses. The chapters that straddle this core provide a brief history and introduction to the methods and basic results of sensory scaling, a detailed example of how scaling was used to examine one particular substantive issue in the domain of sensory processes, and some theoretical issues that arise in the realm of sensory scaling.

There are many people to whom I am indebted. Foremost are S. S. Stevens and Joseph C. Stevens, who have served in several roles: teachers, critics, and models. Special thanks go to Joseph C. Stevens, William S. Cain, Marc H. Bornstein, and Linda M. Bartoshuk for reading and evaluating the mansucript. Mrs. Carol Mikalavicius performed the unenviable task of typing the manuscript amidst a plethora of other duties. Mrs. Fenna Bouhuys prepared the graphs.

The last word is reserved for my wife, who persevered with me through the many years of work that led to the book's completion—not just through the last few years of work on the manuscript itself, but also through the formative years.

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Chapter 1

INTRODUCTION TO SENSORY SCALING

The author's favorite lunchtime restaurant is quite dimly lit: Upon emerging from it, objects on the street, illuminated by the afternoon sun, are almost painfully bright.

One of the author's friends complains that various substances—orange juice, cigarettes—remain unpleasant tasting for a period of time after using toothpaste.

A finger or elbow dipped in a heated bath feels only slightly warm in comparison to the massive thermal sensation experienced when the entire body is immersed.

Certain odors linger in a room almost independently of the amount of fresh air that is introduced, whereas other odors disappear rapidly when so diluted in concentration.

Such a list could be collected and added to almost indefinitely. Most or all of the phenomena just described (or variants of them) should be familiar to the reader. They are examples of sensory phenomena, phenomena that reflect the ways the sense organs operate on signals that impinge upon them. In fact, all of these phenomena are reflections or examples of basic, fundamental properties of human sensory systems. A primary concern of this book is to elucidate such fundamental properties as temporal adaptation and spatial summation.

How does brightness decline with time after initial exposure to light? How does warmth increase as more and more fingers are immersed into heated water? These are *psychophysical* questions. That is, they deal with the relations between psychological or sensory quantities on the one hand and physical or stimulus quantities on the other: brightness versus time, warmth versus area, and so on. Our major concern is with what has been dubbed the "new psychophysics." What is the new psychophysics? Quite simply, it consists of attempts to answer *directly* the aforestated questions! Thus, an answer to the first question might be that brightness declines exponentially with duration of the stimulus. In order to answer psychophysical questions in this manner, it is necessary to quantify both the stimulus variables and the response variables. In order to say that magnitude of warmth sensation is proportional to area, for instance, not only must we be able to measure area (in square centimeters, say), but also to measure warmth (in subjective units).

New versus Old Psychophysics

New Psychophysics

Fundamental to the new psychophysics is the view that human subjects can make meaningful evaluations of the magnitudes of their sensory experiences, at least under certain conditions. The primary developer of methods for evaluating sensory magnitudes is S. S. Stevens, a man whose assiduous interest in measurement and sensory processes dates back to the early 1930s. Stevens has developed and elaborated methods—often called direct scaling methods—for determining magnitudes of sensations. Whereas measurement of stimulus magnitudes may be difficult at times, the principles of measurement have been well worked out. Unfortunately, the same cannot be said for measurement of sensations. But the last two decades have seen great strides made in the quantification of sensory responses, e.g., to saying how many times one sensation is as great as another. This is the domain of the new psychophysics.

Old Psychophysics

Attempts to measure sensation and to relate sensory to stimulus magnitudes have at least two centuries of history. The first quantitative statement (to the best of the author's knowledge) appeared in the eighteenth century, when Krüger (1743) proposed that sensation grows proportionally in its strength with increases in stimulus strength. And the first empirically based "law"—Fechner's logarithmic rule—appeared more than a century ago. Nevertheless, for many years the main thrust of attempts to measure (quantify) sensations and to relate sensations to stimuli fell under the rubric of what may be termed the "old psychophysics." The viewpoint of the old psychophysics was that it is meaningless, difficult, or unimportant to measure sensation directly. So, instead, we measure the stimulus. Take, for example, the question, "How does brightness decrease with time after initial exposure?" One way to assess the decline is to present the test (adapting) light to one eye and a comparison light to the other. The comparison light flashes on briefly, every 5 sec, say, and the subject's task is to adjust its intensity to match the brightness of the test light that is seen continuously. At onset, prior to any adaptation, the comparison will be adjusted to be equal in intensity to the test light. But as time goes on, and the brightness of the test light declines, the intensity of the comparison, adjusted so as to equal the brightness of the test light, must also diminish. The extent of diminution gives a measure of "brightness adaptation."

This sort of measurement—done in accordance with the old psychophysics—for decades dominated the study of the senses. In fact, it still holds sway, providing a lion's share of the information about sensory functioning. But, as this book will attempt to document, more and more research in recent years has shown the limitations imposed by the very nature of the old psychophysics, and, concomitantly, the advantages that often accrue to the use of methods of the new psychophysics.

Obviously, in the sort of measurement of brightness adaptation just described, we do not really have a measure of the magnitude of brightness sensation. All we can say is, for example, that after 2 min of viewing a continuous stimulus, its brightness appears the same as the brightness of a flash of light that is one-eighth (or whatever) as intense. The old psychophysics relied on the method of *intrasensory matching*. What the new psychophysics adds to our knowledge is the relation between brightness and intensity. Thus if we know that an eightfold change in intensity corresponds to a twofold change in brightness, we can conclude that after 2 min of viewing, the brightness fell to a level one-half the initial brightness value.

There is another important approach under the rubric of the old psychophysics, one that deserves special mention. That approach consists of the determination of *sensory invariances*. In the example given above, the time course of adaptation is determined by varying the intensity of a comparison stimulus in order to follow the changing level of brightness. To determine sensory invariance or equivalence, it is necessary to find out how two variables interact to maintain a *constant sensory experience*. For example, adaptation might be studied by maintaining constant the intensity of the comparison light, but adjusting the intensity of the test light over time in order to keep its brightness at the same constant level as that of the comparison. This latter sort of measurement employs the subject as a "null instrument." One purpose of this approach is to avoid some of the problems that arise from nonlinear transformation between stimulus and sensation magnitudes. As we just saw, with the previous procedure (tracking the course of brightness over time), it is necessary to know the psychophysical relation between brightness and intensity of flashes of light in order to understand how brightness diminishes; with the null method, that problem is avoided, since brightness does not change. Thus, the null approach may be considered as the opposite end of the spectrum from the approach of the new psychophysics.

Psychophysical, Sensory–Physical, and Psychosensory Measurement

Perhaps most important to keep in mind is that all of these types of "sensory measurement"—of the old and of the new psychophysics—are mutually complementary. "Psychophysics" as a term encompasses all of these, as well as several other, approaches to the study of sensation. That use of the term psychophysics is a broad one. We may speak of psychophysics in the narrow sense, however, as the study of *stimulus* and *sensation.* Then, the term *psychophysics* in the narrow sense refers only to what we have called the new psychophysics, i.e., to studies of the relations between sensation and stimulus when both are measured as quantities. It becomes convenient in that case to look for another term to describe the old psychophysics. The term to be employed here is *sensory physics.* Sensory physics is defined here to refer to the evaluation of sensory responses purely in terms of measurements of variations in the corresponding physical stimuli. There exists a third category of relationships under the broad term, psychophysics; this third category also arose as a result of the new psychophysics. It consists of *psychosensory* measurement, the determination of interrelations among sensory variables without regard to how they may depend on the stimulus. We have few examples of psychosensory data, however, so the concept is at present of more formal than practical interest. Some examples appear in Chapter 5 (binaural additivity of loudness) and in Chapter 6 (relations among the auditory attributes of loudness, volume, and density).

Early Attempts to Quantify Sensation

As was already mentioned, interest in the quantitative relations between sensation and stimulus well predates the new psychophysics. The greatest impetus to that interest was the publication in 1860 of G. T. Fechner's *Elemente der Psychophysik,* which propounded the notions that sensory intensities could be measured and that the fundamental relation between sensation and stimulus intensities is logarithmic. Unfortunately, attempts at quantification of sensory magnitudes have often led to much rancor and interminable "philosophical" types of dispute, the outcome of which was usually little or no gain in understanding how sensory systems operate. At the point in his textbook where consideration of Fechner's work became appropriate, William James (1892) commented, "Fechner's psycho-physic formula, as he called it, has been attacked on every hand; and as absolutely nothing practical has come of it, it need receive no farther notice here [p. 22]."

It is worthwhile mentioning that psychologists have not been alone in their interest in the measurement of sensory magnitudes. Workers concerned with the application of knowledge in sensory psychophysics, such as acoustical engineers, have often found themselves looking for answers to psychophysical questions of this nature. In fact, it is probably not unfair to state that, to a large extent, the continued interest in the relation between sensory magnitudes and stimulus intensities through the early decades of this century was the result of dissatisfaction among acoustical workers with Fechner's logarithmic psychophysical law.

Among acoustical engineers it had become popular to use decibel notation. Since the decibel is a logarithmic measure of relative energy flow, it had become common, because of Fechner's logarithmic law, to treat the decibel scale of sound energy as a scale of sensory intensity, or loudness. Fletcher for a period of time used the decibel as a unit of loudness (see Fletcher & Munson, 1933). Starting at absolute threshold, constant increases in decibels were assumed to correspond to constant increases in loudness. But the logarithmic (decibel) law was clearly unsatisfactory. Churcher wrote in 1935,

> In common with others engaged on noise problems, the experience of the author and his colleagues over many years is that the numbers assigned by the decibel scale to represent sensation magnitudes are not acceptable to introspection as indicating their relative magnitudes. Two instances will suffice. The loudness of the noise of a motor assessed at 80 dB above threshold in terms of a pure reference tone is, to introspection, enormously greater than twice that of a motor assessed at 40 dB. In some experiments on the reduction of the noise of a geared turbo generator, successive measured values of 104 and 100 dB were obtained or what would ordinarily be taken to indicate a 4 percent reduction in loudness. However, to the ear the loudness reduction appeared much greater than 4 percent and an onlooker who knew nothing of the measurements volunteered the opinion that the reduction was about 20 percent. On other evidence we know that it was actually about 27 percent [p. 217].

Had Fechner's logarithmic law been less egregiously at variance with direct experience, no doubt there would have been much less an impetus to