

Fechner, Gustav Theodor

Introductory article

Stephen Link, University of California, San Diego, California, USA

CONTENTS

Introduction
Life and works

Theory of mental judgment
Conclusion

Gustav Theodor Fechner (1801–1887) was a German physicist and philosopher whose application of mathematical and scientific methods to psychological theory established the science of psychophysics and laid the foundations of experimental psychology.

INTRODUCTION

'In general, the clergy was strongly represented among our relatives, and I was also supposed to embark on this path, but somehow it turned out differently.' Gustav Fechner, son and grandson of pastors, was born on 19 April 1801 in the Saxony village of Großsärchen, now Zarki-Wielkie in Poland. At age 16 he matriculated at Leipzig University, where he spent 70 years first as a medical student, then as professor, chemist, physicist, psychophysicist, estheticist, nature philosopher, poet and satirist (Figure 1). His many theoretical and empirical discoveries enhanced the field of physics and created a basis for statistical hypothesis testing,



Figure 1. Gustav Theodor Fechner (1801–1887).

descriptive statistics, experimental psychology and experimental esthetics.

LIFE AND WORKS

Following the Magisterexamen (rigorosum) at Leipzig University in 1823, Fechner spent ten years developing the theory of electricity, and his important experiments on Ohm's law that made him famous. His translations into German of books by the greatest French physicists of his day gave him the opportunity to meet them personally, to expand on their works and, in 1832, to publish the three-volume *Repertory of Experimental Physics*. These achievements led to his appointment as Professor in Ordinary at Leipzig University in 1834, the establishment of the Institute of Physics in Leipzig, and researches into the perception of color and afterimages.

In December 1839, overwork brought on by voluminous publications including the eight-volume, 7000-page *Hauslexicon* in 1837, and blindness caused by staring directly into sunlight to create vivid afterimages, led to a complete nervous collapse. Ellenberger characterized Fechner's illness as a 'sublime hypochondriasis, a creative illness from which a person emerges with a new philosophical insight and a transformation in their personality'. William James, a close follower of Fechner's work, described the illness as a 'habit neurosis'. For three years Fechner lived as a recluse, wearing a lead eye mask to prevent the pain caused by even the slightest illumination of his damaged eyes. His thoughts became uncontrollable, and his inability to consume food or liquids left him a skeleton near death.

Three years later, however, Fechner miraculously recovered. A transformation of his personality evidenced itself in his writings on the first law of the mind, 'the pleasure principle of action'. In 1846 Fechner argued that the search for pleasure and the avoidance of unpleasure were forces driving human behavior, in *Über das höchste Gut* (On the

highest good). The ideas appear fixed in *Über das Lustprincip der Handelns* (1848). In 1848, his famous *Nanna, oder über das Seelenleben der Pflanzen* (On the soul life of plants) proposed that ‘one can ask whether such a life (of animate creatures) pertains also to the plants, whether they too are animate individuals, combining in themselves impulses or sensations, or maybe more psychic experiences If this were so then plants along with men and animals would constitute a common contrast to stones and all things we call dead.’

Expanding on the idea of consciousness, in 1851 Fechner rendered a new version of *Zend-Avesta*, the sacred writings of the Persian prophet Zarathustra (Zoroaster). Fechner’s *Zend-Avesta, über die Dinge des Himmels und des Jenseits: vom Standpunkt der Naturbetrachtung* (About heavenly things and the hereafter from the standpoint of contemplating nature) proposed that all life forms were self-aware and conscious. Even more, consciousness was in all and through all things. The Earth itself was conscious. Fechner also revealed that when he awoke on 22 October 1850 (now known as Fechner Day), he saw a relation between the body and mind, between the physical and mental, that became the basis for a new science and the first methods of mental measurement.

In particular, Fechner observed that a just noticeable difference (JND) in sensation is felt when a new stimulus increases in magnitude by a fixed proportion of the stimulus against which it is compared. For example, if a 312 g weight feels just noticeably different from a 300 g weight, then a 624 g weight will feel just noticeably different from a 600 g weight. Each JND is a unit of experience, as important to psychology as the mole is to chemistry or the quantum to physics.

Defining stimulus magnitude as a value S , and a just noticeable increment in stimulus magnitude as a value ΔS , Fechner developed the equation known as Weber’s law:

$$\Delta S/S = \text{constant} \quad (1)$$

Fechner generalized this principle, and proposed that even smaller units of $\Delta S/S$ may be added together to create a measure of sensation magnitude. Letting dS represent a small increment in stimulus, Fechner created the differential equation

$$dS/S = \text{constant} \quad (2)$$

Integrating this equation adds together small relative increases in stimulation to form a total amount of sensation. The result is one of the most famous laws in psychology, relating sensation magnitude

ψ to physical stimulus magnitude S , known as Fechner’s law:

$$\psi = \log_e S \quad (3)$$

This formula set Fechner on a voyage of scientific discovery that marked the origin of experimental psychology.

THEORY OF MENTAL JUDGMENT

In *Elemente der Psychophysik*, published in 1860, the future of experimental psychology was set. In this two-volume, 907-page work, Fechner created the theory of judgment and methods of experimentation that still dominate psychological research. Fechner discovered that when comparing two stimuli, such as weights, a person could feel a just noticeable difference in weight but err in judging which of the two weighed more. For example, weights of 300 g and 312 g might feel just noticeably different but the 300 g weight might be judged heavier than the 312 g weight. This paradox led Fechner to propose a theory of judgment that predates the modern theory of statistical hypothesis testing.

In this regard, Fechner assumed that the sensory system is the mind’s connective tunnel to the external world. A sensation or feeling such as heaviness must derive from the process of transforming into neural energy the energy of a physical stimulus. However, Fechner also assumed that the electrochemical sensory measurement system was not perfect. It suffered from the same form of inherent variability in measurement as Gauss had proposed in 1809 to affect physical measurement devices.

As shown in Figure 2, the transformation of weight to heaviness generates a Gaussian probability distribution of heaviness values. The true heaviness of a fixed 300 g weight equals $h(300)$, but because of sensory variability, the actual feeling of heaviness varies. Sometimes the weight feels heavier – and sometimes lighter – than the true heaviness of $h(300)$. Similarly, the true heaviness of a 312 g weight equals $h(312)$, but its heaviness varies according to the probability distribution shown in the upper part of Figure 2. The spread of heaviness values surrounding the mean values of $h(300)$ and $h(312)$ is characterized by the standard deviation of the Gaussian distribution, often denoted σ . Fechner suggested that this sensory variability was the basis for errors of judgment. As a theoretician, Fechner devised a theory of errors of judgment that allowed for a scientific measure of the unknown amount of sensory variability, σ .

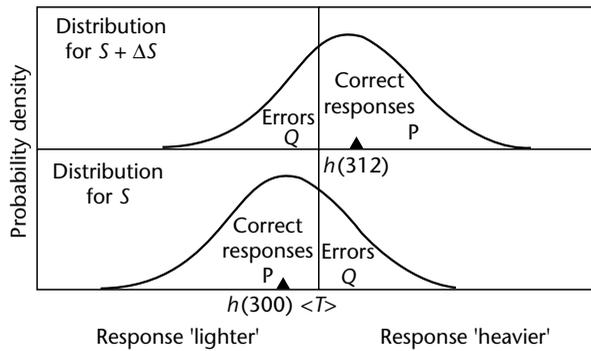


Figure 2. Fechner characterized the unseen variability within the nervous system as a Gaussian (normal) distribution. The abscissa represents heaviness, a psychological phenomenon. Two weights of 300 g and 312 g respectively generate average heaviness values of $h(300)$ and $h(312)$. The average of the two true heaviness values $h(300)$ and $h(312)$ equals T and is the threshold used (on the average) to determine which weight feels heavier.

The theory of judgment assumes that when two weights are compared, the average of the two heaviness values serves as a threshold for deciding which stimulus is heavier (or lighter). The stimulus that produces a heaviness greater than the average heaviness is judged to be the physically greater stimulus (*Elemente*, vol. 1). Converting these ideas into a mathematical form produces a measurement of the amount of variability in the nervous system in units of the physical stimulus. This extraordinary achievement, the first mental measurement, established psychology as a scientific discipline.

Figure 2 illustrates the essential features of Fechner's decision theory. Two weights of 300 g and 312 g are under comparison. On each comparison trial, the participant lifts each stimulus, experiences a sense of heaviness for each weight, and then reports which stimulus is greater in weight. According to the theory, Gaussian distributed variability perturbs the measure of heaviness. These distributions are shown in Figure 2 with heaviness means equal to $h(300)$ and $h(312)$. The threshold (criterion) for deciding which weight was heavier will change from trial to trial because the same heaviness values will not occur with each lifting of the weights. On the average, however, the threshold for deciding which weight is heavier is the average of the two mean heaviness values, equal to the value T shown in Figure 2.

The area to the right of T and under the Gaussian distribution for the heaviness of 312 g equals P . This is the probability of correctly judging the 312 g weight to be the larger weight. Also, the area Q , to the right of the criterion under the Gaussian

distribution for the 300 g weight, equals the probability of an error in judging the smaller weight of 300 g to be the larger. Owing to the mirror symmetry of the Gaussian distributions with respect to T , and the requirement that areas under probability distributions must sum to 1, the values of P and Q must sum to 1.0. For a larger weight, say 324 g, the distribution of heaviness values shifts to the right. As a consequence, the threshold value T also shifts to the right, causing the value of P to increase and the value of Q to decrease.

To measure the amount of the unseen variability in the nervous system Fechner defined a measure of distance along the abscissa of Figure 2 in terms of the standard deviation, σ . Then he created mathematical tables showing how many errors of judgment occur for any value of T as measured in numbers of standard deviation units, σ . By running experiments to determine the probability of an error of judgment, and by comparing the error probability to entries of T in his tables, Fechner determined the number of standard deviation units separating T from $h(300)$. Using the Newtonian assumption that for very small differences in heaviness the function h is approximately linear, he determined that the threshold at T equaled $\frac{1}{2}(312 - 300)/\sigma$. Therefore,

$$\sigma = \frac{1}{2}(312 - 300)/T \quad (4)$$

In this way Fechner measured the unseen force that resulted in errors of judgment. In this way he measured the unknown value of σ in units of the physical stimulus. In this way psychology became a science.

Elemente remained the basic work on experimental design until the 1935 appearance of R. A. Fisher's *Design of Experiments*. The theory still finds powerful applications. Thurstone developed a theory equivalent to Fechner's that yielded psychological measurement scales for such diverse stimuli as the seriousness of crimes, likeableness of vegetables and attitudes generally. The signal detection theory formulated by Tanner and Swets in 1954 allowed the value of T to vary as a function of experimenter inducements to bias judgments toward one response. Kinchla and Smyzer extended Fechner's theory in 1967 by providing a theory of visual position memory that predicted linear increases in σ^2 as a function of time.

The 'mirror effect' in recognition memory can be interpreted as a shift of Gaussian distributions of the memory strength along an abscissa of memory strength. As one distribution for memory strength shifts toward higher values, due to increased memory strength, the value of T must also shift

and the value of P in Figure 2 must increase while the value of Q must decrease. Stretch and Wixted showed that the value of T increases as word recognition memory strengthens, as Fechner's decision theory requires.

Elemente Volume 2 defines Fechner's law and describes 'inner psychophysics', the study of mind without regard to its sensory connections. The application of Weber's law, Fechner's law, and the threshold to inner psychophysics results in ideas about sleep and being awake, partial sleep, attention, and consciousness. Other chapters describe the wave scheme, relations between sensory and imagery phenomena, memory images, memory afterimages, the phenomena of sensory memory, psychophysical continuity and noncontinuity, hallucinations, illusions and dreams. Some fifty years later, Sigmund Freud commented, 'I... have followed that thinker on many important points.'

During his last 27 years Fechner created the field of experimental esthetics, continued his psychophysical investigations, and introduced ideas about descriptive statistics. In 1866 *Das Assoziationsprincip in der Aesthetik* foreshadowed *Zur experimentellen Aesthetik* (1871) and the establishment of the field of experimental esthetics with the two-volume *Vorschule der Aesthetik* in 1876. Modern works on esthetic judgments by Beebe-Center, Hare, and Dorfman and colleagues extend and apply Fechner's and Thurstone's theories to art and emotion.

Returning to psychophysics, in 1877 Fechner published *In Sachen der Psychophysik*, in 1882 *Revision der Hauptpunkte der Psychophysik*, and in 1884 two more major experimental works. At Wilhelm Wundt's urging G. F. Lipps edited and published, posthumously, Fechner's last work *Kollektivmasselehre* (1897) a theory of data analysis that coined the term 'descriptive statistics'.

CONCLUSION

Fechner called upon the world to recognize the fundamental unity of the mind and physical reality. His many theoretical ideas changed over time and yet became foundations for a century and more of research and theory. What would psychology be without Fechner's psychophysics, without such important developments as signal detection theory, psychoanalysis, experimental memory, and attention and esthetics? Each of these mighty fields owes much to Fechner's originality of thought, integration of psychological theory with mathematics and experimental design, and firm belief that the physical and mental worlds form a single reality.

Further Reading

- Anderson NH (1982) *Methods of Information Integration Theory*. New York: Academic Press.
- Beebe-Center JG (1932) *The Psychology of Pleasantness and Unpleasantness*. New York: Van Nostrand.
- Dorfman LYa, Leontiev DA, Petrov VM and Sozinov VA (1992) *Emotions and Art*. Perm: Institute for Arts and Culture.
- Ellenberger HF (1970) *The Discovery of the Unconscious: The History and Evolution of Dynamic Psychiatry*. New York: Basic Books.
- Falmagne JC (1985) *Elements of Psychophysical Theory*. New York: Oxford University Press.
- Fechner GT (1966) *Elements of Psychophysics*, vol. 1, translated by HE Adler. New York: Holt, Rinehart & Winston. [Original work published 1860.]
- Freud S (1935) *Autobiography*, translated by J. Strachey. New York: WW Norton.
- Gauss CF (1809) *Theoria Motus Corporum Caelestium*. Hamburg: Certhes & Besser.
- Gescheider GA (1997) *Psychophysics: The Fundamentals*. Mahwah, NJ: Erlbaum.
- Green DM and Swets JA (1966) *Signal Detection Theory and Psychophysics*. New York: John Wiley.
- Hare WF (1967) *Modern Aesthetics*. New York: Teachers College Press.
- Kinchla RA and Smyzer F (1967) A diffusion model of perceptual memory. *Perception and Psychophysics* 2: 219–229.
- Laming DRJ (1986) *Sensory Analysis*. Orlando: Academic Press.
- Link SW (1992) *The Wave Theory of Difference and Similarity*. Mahwah, NJ: Erlbaum.
- Link SW (1992) Rediscovering the past: Gustav Fechner and signal detection theory. *Psychological Science* 5: 335–340.
- Lowrie W (1946) *Religion of a Scientist: Selections From The Religious Writings of Gustav Theodor Fechner*. New York: Pantheon Books.
- Luce RD (2000) *The Utility of Gains and Losses*. Mahwah, NJ: Erlbaum.
- Macmillan NA and Creelman CD (1991) *Detection Theory: A User's Guide*. New York: Cambridge University Press.
- Marks LE (1974) *Sensory Processes: The New Psychophysics*. New York: Academic Press.
- Norwich KH (1993) *Information, Sensation, and Perception*. San Diego: Academic Press.
- Sommerfeld E, Kompass R and Lachman T, eds (2001) *Fechner Day 2001*. Lengerich: Pabst.
- Stevens SS (1975) *Psychophysics*. New York: John Wiley.
- Stretch V and Wixted JT (1998) On the difference between strength-based and frequency-based mirror effects in recognition memory. *Journal of Experimental Psychology, Learning, Memory and Cognition* 24(6): 1–18.
- Tanner WP and Swets JA (1954) A decision making theory of visual detection. *Psychological Review* 61(6): 401–409.
- Thurstone LL (1955) *The Measurement of Values*. Chicago: University of Chicago Press.
- Vickers D (1979) *Decision Processes in Visual Perception*. New York: Academic Press.