UNIVERSITY OF CHEMISTRY AND TECHNOLOGY, PRAGUE
Faculty of Food and Biochemical Technology
Department of Food Analysis and Nutrition

Lecture II - Sensory law

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The aim of the lecture - what to know

Major points:

Psychometric

Psychophysics

Weber law

Fechner law

Stevens' power law

Psychophysics

- It is the branch of psychology, can be describe as "the scientific study of the relation between stimulus and sensation„ , more completely, as "the analysis of perceptual processes by studying the effect on a subject's experience or behaviour of systematically varying the properties of a stimulus along one or more physical dimensions

- *Psychophysics* quantitatively investigates the relationship between physical stimuli and the sensations and perceptions they produce.

- *Psychophysics* also refers to a general class of methods that can be applied to study a perceptual system. Modern applications rely heavily on threshold measurement, ideal observer analysis, and signal detection theory.

Classical psychophysical method

Psychophysical experiments have traditionally used **three methods for testing subjects**' perception in stimulus detection and difference detection experiments: the method of limits, the method of constant stimuli and the method of adjustment

Method of limits

In the ascending method of limits, some property of the stimulus starts out at a level so low that the stimulus could not be detected, then this level is gradually increased until the participant reports that they are aware of it.

For example, if the experiment is testing the minimum amplitude of sound that can be detected, the sound begins too quietly to be perceived, and is made gradually louder. In the descending method of limits, this is reversed. In each case, the threshold is considered to be the level of the stimulus property at which the stimuli are just detected.

In experiments, the ascending and descending methods are used alternately and the thresholds are averaged. A possible disadvantage of these methods is that the subject may become accustomed to reporting that they perceive a stimulus and may continue reporting the same way even beyond the threshold (the error of habituation).

Conversely, the subject may also anticipate that the stimulus is about to become detectable or undetectable and may make a premature judgment (the error of anticipation).

To avoid these potential pitfalls, Georg von Békésy introduced the staircase procedure in 1960 in his study of auditory perception. In this method, the sound starts out audible and gets quieter after each of the subject's responses, until the subject does not report hearing it. At that point, the sound is made louder at each step, until the subject reports hearing it, at which point it is made quieter in steps again. This way the experimenter is able to "zero in" on the threshold.

Threshold determination

⇨ ***Procedure for the quantitative determination of the taste and/or smell sensibilities of panelists***

Detection threshold (absolute threshold):

The presence of the stimulus can be noticed, but the stimulus cannot be recognised.

('There is anything, but I do not know what it is.')

Recognition threshold:

The stimulus is noticed and recognised.

('There is something and it is sweet.')

Difference threshold:

Differences between neighbouring samples can be perceived.

('Sample A is sweeter than sample B.')

Terminal threshold:

Samples with different concentrations cannot be differentiated due their intensity.

('Both samples are sweet, I cannot say which one is sweeter.')

Method of constant stimuli

Instead of being presented in ascending or descending order, in the method of constant stimuli the levels of a certain property of the stimulus are not related from one trial to the next, but presented randomly.

This prevents the subject from being able to predict the level of the next stimulus, and therefore reduces errors of habituation and expectation. For 'absolute thresholds' again the subject reports whether he or she is able to detect the stimulus.

For 'difference thresholds' there has to be a constant comparison stimulus with each of the varied levels.

Friedrich Hegelmaier described the method of constant stimuli in an 1852 paper. This method allows for full sampling of the psychometric function, but can result in a lot of trials when several conditions are interleaved.

Method of adjustment

- The method of adjustment asks the subject to control the level of the stimulus, instructs them to alter it until it is just barely detectable against the background noise, or is the same as the level of another stimulus.

- This is repeated many times. This is also called the method of average error. In this method the observer himself controls the magnitude of the variable stimulus beginning with a variable that is distinctly greater or lesser than a standard one and he varies it until he is satisfied by the subjectivity of two. The difference between the variable stimuli and the standard one is recorded after each adjustment and the error is tabulated for a considerable series. At the end mean is calculated giving the average error which can be taken as the measure of sensitivity.

EDUARD WILHELM WEBER

24. 10. 1804 - 23. 6. 1891 Wittenberg

As a student of twenty years he, with his brother, Ernst Heinrich Weber, Professor of Anatomy at Leipzig, had written a book on the *Wave Theory and Fluidity,* which brought its authors a considerable reputation

In 1831, (at the age of twenty-seven) on the recommendation of Carl Friedrich Gauss, Weber was hired by the University of Göttingen as professor of physics. His lectures were interesting, instructive, and suggestive.

Acoustics was a favourite science of his, and he published numerous papers.

The 'mechanism of walking in mankind' was another study, undertaken in conjunction with his younger brother, Eduard Weber. These important investigations were published between the years 1825 and 1838.

Gauss and Weber constructed the first electromagnetic telegraph in 1833, which connected the observatory with the institute for physics in Göttingen.

One of his most important works, co-authored with Carl Friedrich Gauss and Carl Wolfgang Benjamin Goldschmidt, was *Atlas des Erdmagnetismus: nach den Elementen der Theorie entworfen* (*Atlas of Geomagnetism: Designed according to the elements of the theory*), a series of magnetic maps, and it was chiefly through his efforts that magnetic observatories were instituted.
He studied magnetism with Gauss, and during 1864 published his *Electrodynamic Proportional Measures* containing a system of absolute measurements for electric currents, which forms the basis of those in use.

Weber died in Göttingen, where he is buried in the same cemetery as Max Planck and Max Born.

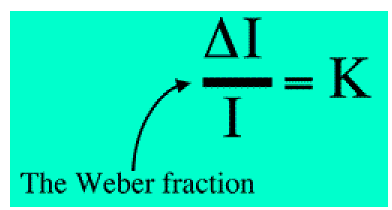
Weber law

Ernst Heinrich Weber postulated that ‘just noticeable stimuli’ are proportional to the magnitudes of the stimuli.

If you lift up and hold a weight of 2.0 kg, you will notice that it takes some effort. If you add to this weight another 0.05 kg and lift, you may not notice any difference between the apparent or subjective weight between the 2.0 kg and the 2.1 kg weights. If you keep adding weight, you may find that you will only notice the difference when the additional weight is equal to 0.2 kg. The increment threshold for detecting the difference from a 2.0 kg weight is 0.2 kg. The just noticeable difference (jnd) is 0.2 kg.

Now start with a 5.0 kg weight. If you add weight to this, you will find that the just noticeable difference is 0.5 kg. It takes 0.5 kg added to the 5.0 kg weight for you to notice an apparent difference.
For the weight of magnitude, I, of 2.0 kg, the increment threshold for detecting a difference was a ΔI (pronounces, delta I) of 0.2 kg.
For the weight of magnitude, I = 5.0 kg, the increment threshold ΔI = 0.5 kg.
The ratio of $\Delta I/I$ for both instances (0.2/2.0 = 0.5/5.0 = 0.1) is the same. **This is Weber's Law.**

Weber's Law: over a large dynamic range, and for many parameters, the threshold of discrimination between two stimuli increases linearly with stimulus intensity.



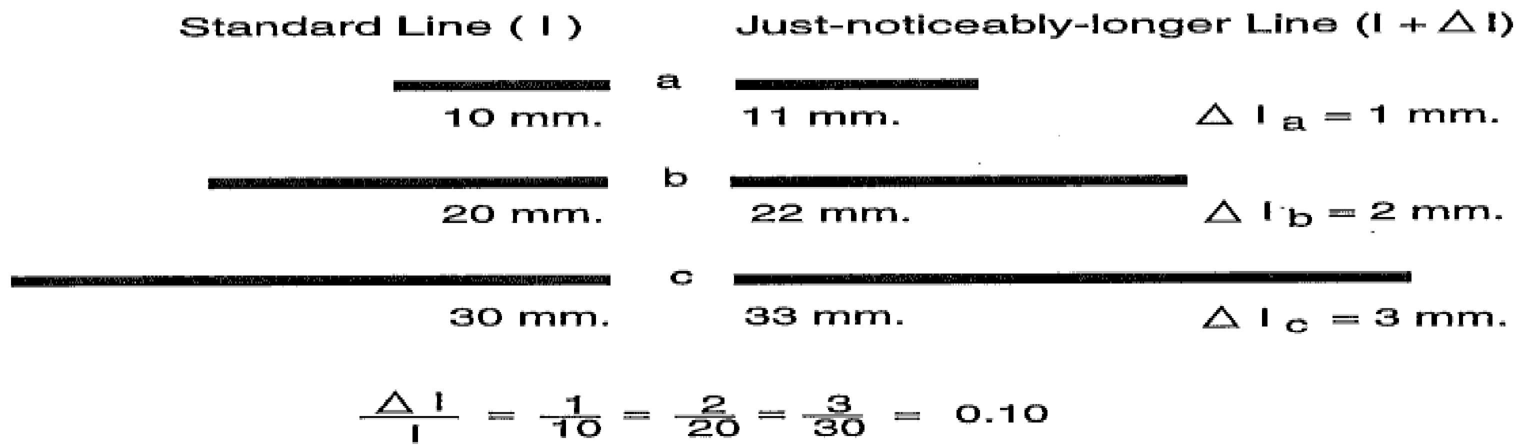


Figure A.3.1 Just noticeable differences (jnds) at different stimulus magnitudes for line length. At 10 mm, an additional 1 mm of length is needed to detect a difference; at 20 mm, an additional 2 mm; and at 30 mm an additional 3 mm. Thus, the ratio of additional length required (ΔI) to the stimulus magnitude (I) is constant at a value of 0.1.

Calculation of Weber law.

The initial intensity (the intensity before adding the increment) is I, and the amount needed to detect a difference ΔI.

In a discrimination experiment, we are interested in measuring ΔI as a function of I. We want to find the discrimination threshold ΔI such that a stimulus with an intensity I+ ΔI is just discriminable from a stimulus of intensity I.

Weber's law characterizes how the ΔI we measure depends on I.
It states that $\Delta I = Kw.I$ for some constant Kw
The constant Kw is called the Weber Fraction. There is the similarity between this equation and the equation for a straight line, $y = m * x + b$.
Weber's law expresses the equation for a straight line, with the slope m being the Weber Fraction, Kw and the y-intercept b being zero. Likewise, I plays the part of x and ΔI plays the part of y.
There are other ways of expressing Weber's law which might allow a more convenient visual analysis of whether or not Weber's law holds for a set of data. The first one described below is that the measured difference thresholds ΔI is divided by the intensity I. $\Delta I/I = Kw$.
The second one converts the discrimination thresholds and the base intensity into logarithms:
$\log(\Delta I) = \log(I) + \log(Kw)$

Some examples of Weber' Law

Weber's Law

- A just noticeable difference is a constant proportion of the intensity of an initial stimulus

Some examples of Weber' Law

Weight	2 %
Brightness	2 %
Loudness	10 %
Taste of salt	10 %

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Gustav Theodor Fechner
*19.4.1801 – †18.11.1887

Fechner’s law

Fechner’s law provides an explanation for Weber’s law. Fechner’s explanation has two parts. The first part is that two stimuli will be discriminable if they generate a visual response that exceeds some threshold.

The second part is that the visual response *R* to an intensity *I* is given by the equation
$R = \log(I)$.

This relation is plotted in the graph. Suppose we call the change in response necessary for discrimination “one”. Then by Fechner’s law the two intensities indicated by arrows will be just discriminable. The discrimination threshold ΔI is given by the distance on the x-axis between *I* and $I+\Delta I$.

Weber-Fechner law

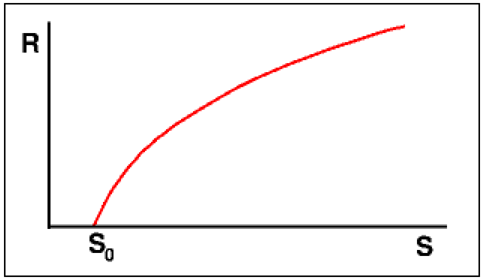
Gustav Theodor Fechner wrote that subjective sensation is proportional to the logarithm of the stimulus intensity.

Later, Gustav Fechner showed how Weber's law could be accounted for by postulating that the external stimulus is scaled into a logarithmic internal representation of sensation. Both scientists considered as one of their central goals the mathematical description of how a continuum of sensation, such as loudness or duration, is represented in the mind. By careful psychophysical experiments, often requiring thousands of discrimination trials on pairs of stimuli, they identified basic regularities of our psychological apparatus.

Since a constant relative difference in the intensity corresponds to a constant absolute difference in the **logarithm** of the intensity, Weber and Fechner suggested that R is proportional to the logarithm of S:

$R = k \log (S/S_0)$

which corresponds to a curve of this type:



The Weber-Fechner law is a crucial link between the physical and perceptual worlds.

Adaptive psychophysical methods

The classic methods of experimentation are often argued to be inefficient. This is because, in advance of testing, the psychometric threshold is usually unknown and much data is collected at points on the psychometric function that provide little information about the parameter of interest, usually the threshold.

Adaptive staircase procedures (or the classical method of adjustment) can be used such that the points sampled are clustered around the psychometric threshold. However, the cost of this efficiency is that there is less information regarding the psychometric function's shape.

Adaptive methods can be optimized for estimating the threshold only, or threshold *and* slope.

Adaptive methods are classified into staircase procedures and Bayesian or maximum-likelihood methods.

Staircase methods rely on the previous response only and are easier to implement. Bayesian methods take the whole set of previous stimulus-response pairs into account and are believed to be more robust against lapses in attention

Stevens' power law

In 1957 Stanley S. Stevens (1906 – 1972) discussed the possibility that the internal scale is a power function rather than a logarithm.

Stevens' power law is generally considered to provide a more accurate and/or general description, although both the Weber - Fechner law and Stevens' power law entail implicit assumptions regarding the measurement of perceived intensity of stimuli. Steven's law says the magnitude of the perceived intensity is related to the magnitude of the physical intensity raised to some power.

:

$$R = c \cdot S^n$$

$$\log R = n \cdot \log S + c$$

where R is the perceived intensity, S is a measure of the physical intensity, and *c* and *n* are constants. One of Steven's main contributions was showing that n varies according to the nature of the stimulus. Some examples of n: are brightness of light n=0.3, saccharin n=0.8, saltiness n%1.0, sucrose n=1.5 (showing that its sweetness is not sensed in the same manner as saccharin’s), temperature n=1.6, electric shock n=3.6.

Bayesian and maximum-likelihood procedures

Bayesian and maximum-likelihood adaptive procedures behave, from the observer's perspective, similar to the staircase procedures.

The choice of the next intensity level works differently, however: After each observer response, from the set of this and all previous stimulus/response pairs the likelihood is calculated of where the threshold lies.

The point of maximum likelihood is then chosen as the best estimate for the threshold, and the next stimulus is presented at that level (since a decision at that level will add the most information).

In a Bayesian procedure, a prior likelihood is further included in the calculation. Compared to staircase procedures, Bayesian and ML procedures are more time-consuming to implement but are considered to be more robust. Well-known procedures of this kind are Quest, ML-PEST, and Kontsevich & Tyler's method.

Magnitude estimation

In the prototypical case, people are asked to assign numbers in proportion to the magnitude of the stimulus.

This psychometric function of the geometric means of their numbers is often a power law with stable, replicable exponent. Although contexts can change the law & exponent, that change too is stable and replicable.

Instead of numbers, other sensory or cognitive dimensions can be used to match a stimulus and the method then becomes "magnitude production" or "cross-modality matching".

The exponents of those dimensions found in numerical magnitude estimation predict the exponents found in magnitude production.

Magnitude estimation generally finds lower exponents for the psychophysical function than multiple-category responses, because of the restricted range of the categorical anchors, such as those used by Likert as items in attitude scales.

Staircases procedures

Staircases usually begin with a high intensity stimulus, which is easy to detect.

The intensity is then reduced until the observer makes a mistake, at which point the staircase 'reverses' and intensity is increased until the observer responds correctly, triggering another reversal.

The values for the last of these 'reversals' are then averaged.

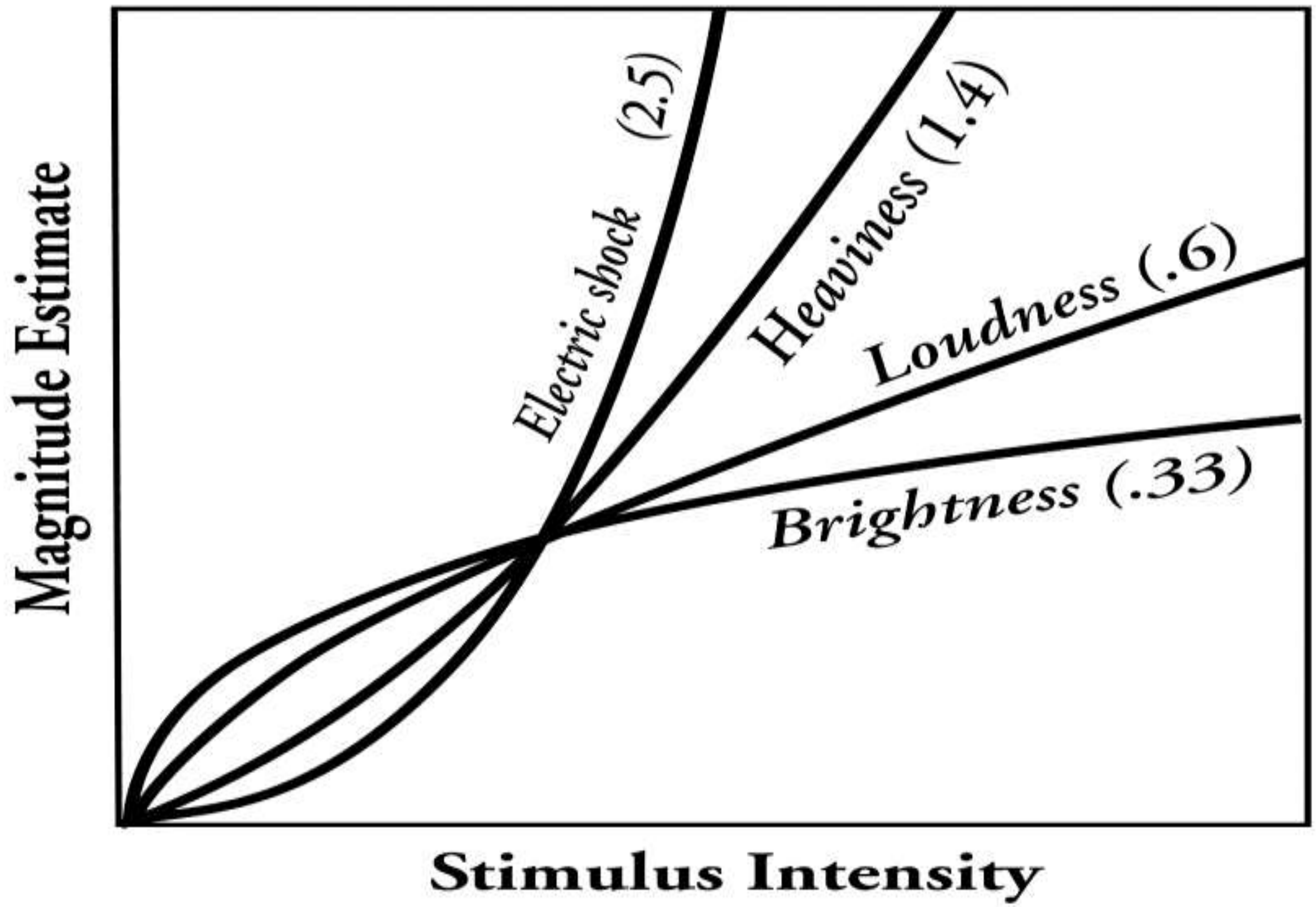
There are many different types of staircase procedures, using different decision and termination rules. Step-size, up/down rules and the spread of the underlying psychometric function dictate where on the psychometric function they converge.

Threshold values obtained from staircases can fluctuate wildly, so care must be taken in their design. Many different staircase algorithms have been modeled and some practical recommendations suggested by Garcia-Perez.

One of the more common staircase designs (with fixed-step sizes) is the 1-up-N-down staircase.

a) If the participant makes the correct response N times in a row, the stimulus intensity is reduced by one step size.
b) If the participant makes an incorrect response the stimulus intensity is increased by the one size. A threshold is estimated from the mean midpoint of all runs. This estimate approaches, asymptotically, the correct threshold.

Stevens law


Electric shock (2.5)
Heaviness (1.4)
Loudness (.6)
Brightness (.33)
Magnitude Estimate
Stimulus Intensity

Psychometric

- Psychometrics is the field of study concerned with the theory and technique of educational and psychological measurement, which includes the measurement of knowledge, abilities, attitudes, and personality traits.
- The field is primarily concerned with the study of measurement instruments such as questionnaires and tests.
- Practitioners are described as psychometricians. Psychometricians usually possess a specific qualification, and most are psychologists with advanced graduate training. In addition to traditional academic institutions, many psychometricians work for the government or in human resources departments. Others specialize as learning and development professionals.

Psychological testing

Psychological testing has come from two streams of thought:

the first, from Darwin, Galton, and Cattell on the measurement of individual differences,

the second, from Herbart, Weber, Fechner, and Wundt and their psychophysical measurements of a similar construct. The second set of individuals and their research is what has led to the development of experimental psychology, and standardized testing

Victorian stream

Charles Darwin was the inspiration behind Sir Francis Galton who led to the creation of psychometrics.

In 1859, Darwin published his book "The Origin of Species", which pertained to individual differences in animals. This book discussed how individual members in a species differ and how they possess characteristics that are more adaptive and successful or less adaptive and less successful. Those who are adaptive and successful are the ones that survive and give way to the next generation, who would be just as or more adaptive and successful. This idea, studied previously in animals, led to Galton's interest and study of human beings and how they differ one from another, and more importantly, how to measure those differences.

Galton wrote a book entitled "Hereditary Genius" about different characteristics that people possess and how those characteristics make them more "fit" than others. Today these differences, such as sensory and motor functioning (reaction time, visual acuity, and physical strength) are important domains of scientific psychology. Much of the early theoretical and applied work in psychometrics was undertaken in an attempt to measure intelligence Galton, often referred to as "the father of psychometrics," devised and included mental tests among his anthropometric measures. James McKeen Cattell, who is considered a pioneer of psychometrics went on to extend Galton's work. Cattell also coined the term *mental test*, and is responsible for the research and knowledge which ultimately led to the development of modern tests. (Kaplan & Saccuzzo, 2010)

German stream

The origin of psychometrics also has connections to the related field of psychophysics. Around the same time that Darwin, Galton, and Cattell were making their discoveries, Herbart was also interested in "unlocking the mysteries of human consciousness" through the scientific method. Herbart was responsible for creating mathematical models of the mind, which were influential in educational practices in years to come.

E.H. Weber built upon Herbart's work and tried to prove the existence of a psychological threshold, saying that a minimum stimulus was necessary to activate a sensory system.
After Weber, G.T. Fechner expanded upon the knowledge he gleaned from Herbart and Weber, to devise the law that the strength of a sensation grows as the logarithm of the stimulus intensity. A follower of Weber and Fechner, Wilhelm Wundt is credited with founding the science of psychology. It is Wundt's influence that paved the way for others to develop psychological testing

20th century

The psychometrician L. L. Thurstone, founder and first president of the Psychometric Society in 1936, developed and applied a theoretical approach to measurement referred to as the law of comparative judgment, an approach that has close connections to the psychophysical theory of Ernst Heinrich Weber and Gustav Fechner. In addition, Spearman and Thurstone both made important contributions to the theory and application of factor analysis, a statistical method developed and used extensively in psychometrics.

In the late 1950s, Leopold Szondi made an historical and epistemological assessment of the impact of statistical thinking onto psychology during previous few decades: "in the last decades, the specifically psychological thinking has been almost completely suppressed and removed, and replaced by a statistical thinking. Precisely here we see the cancer of testology and testomania of today.„

More recently, psychometric theory has been applied in the measurement of personality, attitudes and beliefs, and academi achievement. Measurement of these unobservable phenomena is difficult, and much of the research and accumulated science in this discipline has been developed in an attempt to properly define and quantify such phenomena. Critics, including practitioners in the physical sciences and social activists, have argued that such definition and quantification is impossibly difficult, and that such measurements are often misused, such as with psychometric personality tests used in employment procedures

Short history of psychometric

The history of psychometric is connected with other discipline psychophysics and some of the scientists are famous for both field.

The early theoretical and applied work in psychometrics was undertaken in an attempt to measure intelligence. One of the first scientists in psychometric is Francis Galton who was famous due to his anthropometric measures.

Two other pioneers of psychometrics obtained PhDs in the Leipzig Psychophysics Laboratory under Wilhelm Wundt; James McKeen Cattell in 1886 and Charles Spearman in 1906.

The psychometrician L. L. Thurstone, founder and first President of the Psychometric Society in 1936, developed and applied a theoretical approach to the measurement referred to as the law of comparative judgment, an approach which has close connections to the psychophysical theory developed by Ernst Heinrich Weber and Gustav Fechner.

In addition, Spearman and Thurstone both made important contributions to the theory and application of factor analysis, a statistical method that has been developed and used extensively in psychometrics http://ebookbrowse.com/sensory-evaluation-of-dairy-products-pdf-d228833686

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