EARLY APPARATUS-BASED EXPERIMENTAL PSYCHOLOGY, PRIMARILY AT WILHELM WUNDT'S LEIPZIG INSTITUTE*

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Despite a multitude of contributions to the historiography of early experimental psychology, this topic has rarely been dealt with from an apparatus-oriented perspective. Therefore, this chapter introduces the two most prominent research lines of early apparatus-based experimental psychology with the respective investigations, conducted primarily at Wilhelm Wundt's (1832-1920) Leipzig institute, the world's very first institute of experimental psychology. These two research lines are referred to as *Mental chronometry* and *Attempts to quantify the phenomena of consciousness*, respectively.

Mental chronometry

Mental chronometry was concerned with measuring the time consumed by basic mental operations such as stimulus discrimination or choice of the adequate reaction to a certain stimulus. These chronometric investigations constituted the first coherent research program in experimental psychology. They were inspired on the one hand by inaccurate astronomical observations and on the other hand by the determination of the unexpectedly slow signal propagation velocity in nerves by Hermann von Helmholtz (1821-1894) in the middle of the 19th century. Helmholtz measured the respective velocities at about 30 meters per second in frog nerves and at 60 to 80 meters per second in human nerves[1] (Helmholtz, 1850a, b, 1852).

As the astronomical problems just mentioned are closely related to what we nowadays call the paradigm of distributed attention, this topic will be shortly sketched. In early 1796, Sir Nevil Maskelyne (1732-1811), the Fifth Astronomer Royal at the Greenwich Observatory, dismissed his assistant David Kinnebrook (1772-1802) after only two years on duty. In the end, Kinnebrook's transit recordings of

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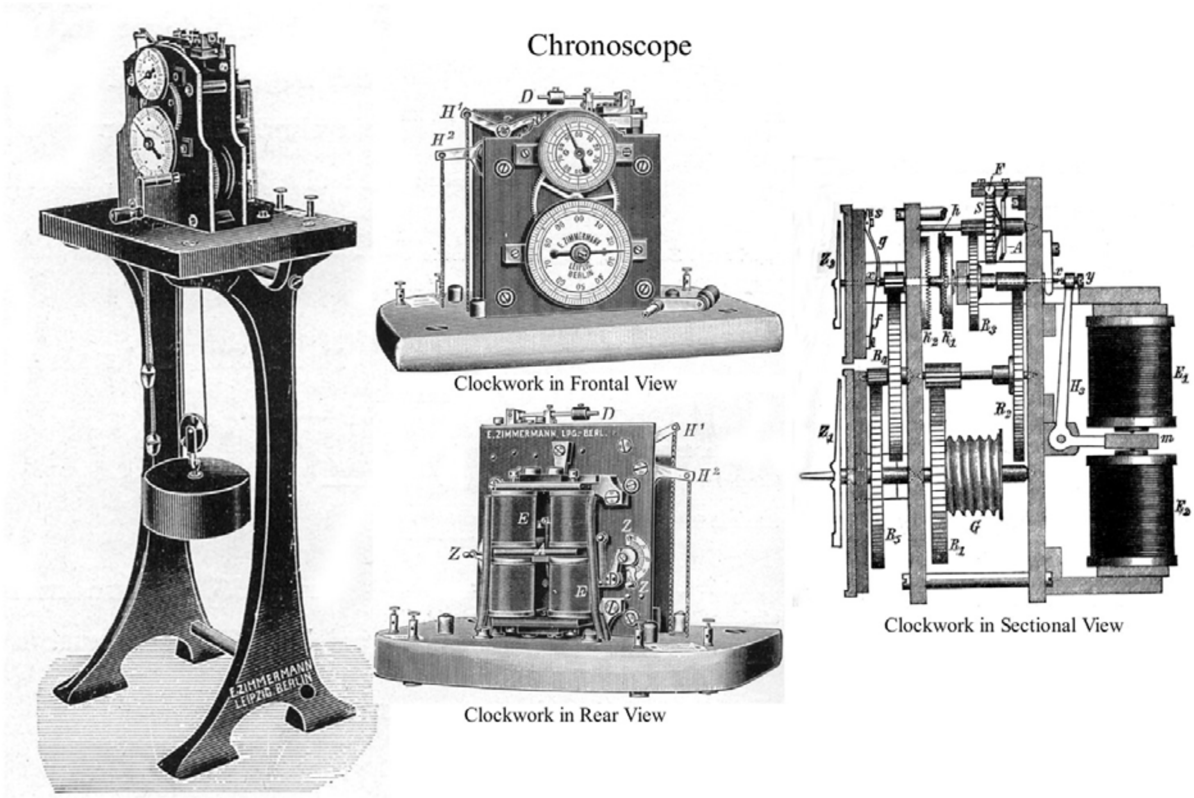
1 To determine the respective velocity in frog nerves, Helmholtz attached a frog muscle with the corresponding efferent nerve to a drawing device. He then stimulated the nerve electrically and produced plots of the muscle contraction over time. From the nerve's length and the latency of muscle contraction he calculated the propagation velocity. For human nerves he determined this velocity by dermal electrical stimulation. This was a seminal work as only a couple of years ago Johannes Peter Müller (1801-1857), another famous German physiologist of the 19th century, had expressed his conviction that this propagation velocity would exceed the range of measurability forever.

celestial objects diverged from Maskelyne's by about eight tenth of a second, for what Maskelyne had no other explanation than Kinnebrook's carelessness. In those transit observations the observer simultaneously had to attend to the beats of a second signal and to the transit of the object through the meridian wire of the telescope. From the object's position at the last beat *before* transit and the first beat *after* transit the observer had to estimate transit time. Apparently, Maskelyne could not imagine that mental operations as listening to the beats of the clock and watching the celestial body on its trajectory are time consuming competitive mental tasks.

In the early 19th century, the famous mathematician und astronomer Friedrich Wilhelm Bessel (1784-1846) made observations by means of a comparable method at the Königsberg Observatory (Prussia), and he found divergences of even more than 1 second between experienced observers (Bessel, 1822). Only now the scientific community was sensitized to the time response of mental operations. While in the following years astronomy eagerly tried to substitute the »inert system« of human information processing by technical devices, physiology and, modestly delayed, experimental psychology concentrated on investigating exactly these relatively inert mental processes quantitatively.

One important technical precondition for measuring these response times was an easy-to-use chronometer with a high resolution, down to the millisecond, if possible. In principle, this instrument was available with Charles Wheatstone's (1802-1872) so-called »chronoscope« from the 1840s. Initially conceived for technical time measurements, chronoscopes (see Fig.1, next page) were clockworks driven by a heavy weight. These devices were started or stopped by closing or opening an electrical circuit into which they were integrated. Wheatstone's chronoscope was essentially enhanced by the German clockmaker Matthias Hipp (1813-1893) in the 1860s by separating the hands of the clock from the clockwork itself. As a result, the inertia of the system was immensely reduced; this brought about a drastic improvement to Wheatstone's chronoscope, in which the complete clockwork had to be started at the beginning and had to be stopped at the end of the time interval to be measured. In Hipp-type chronoscopes the hands were connected to the permanently running clockwork at the beginning of the respective time interval and they were disconnected at the end of this interval by some kind of clutch, implemented by means of two crown wheels (Fig. 1, sectional view, K_1 and K_2). As soon as the electrical circuit was closed, the electromagnets (Fig. 1, rear view, *E*) clutched-in the crown wheels via a lever construction (Fig. 1, sectional view, *m* and H_3). When the voltage broke down, the crown wheels de-clutched and thus stopped the hands showing the elapsed time. The chronoscope was equipped with two dials each of them divided into 100 scale units (Fig. 1, frontal view). The hand of the upper dial made a full turn in a tenth of a second, while the hand of the lower dial made a full turn in 10 seconds. So, the upper dial indicated milliseconds, and the lower indicated tenths of a second. The timer of this device was a spring (Fig. 1, sectional view, *F*) oscillating at 1000 Hertz and so allowing the clockwork to make thousand steps per second.

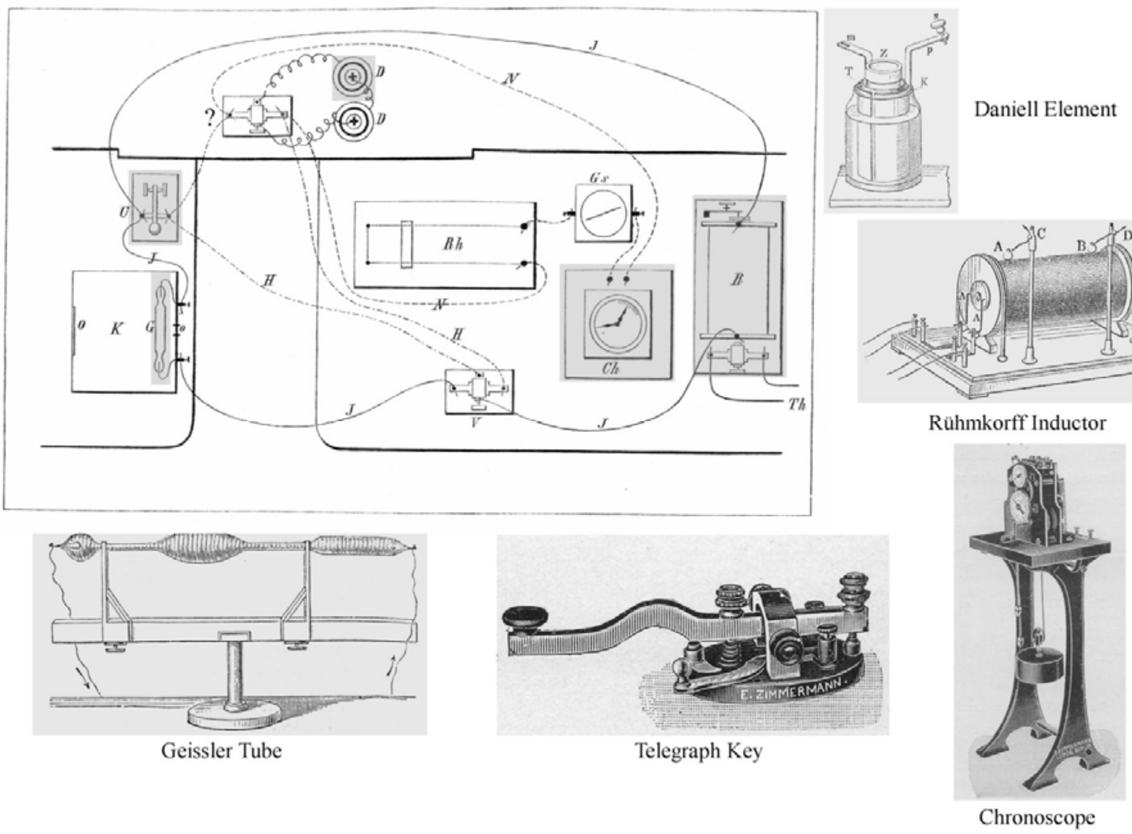


Source: Zimmermann, 1928, p. 110, and Wundt, 1908-11, 3rd vol., p. 369, respectively

Fig. 1: The Hipp-type chronoscope. For a detailed explanation, see the text.

In the 1860s, the astronomer Adolph Hirsch (1830-1901) was the first to use the chronoscope for non-technical time measurements in Neuchâtel (Switzerland). He hereby used two instruments, manufactured by his friend Hipp. Hirsch measured the fastest possible reaction (the purely physiological reaction time) to auditory, visual, and tactile stimulation and determined values of about 200 milliseconds for these three modalities (Hirsch, 1865).

Nearly at the same time the physiologist Frans Cornelis Donders (1818-1889) conducted experiments together with his doctoral student Johan Jacob de Jaager at Utrecht (The Netherlands) to determine the time expenditure for stimulus discrimination and reaction choice by using the so-called »noëmatachograph«, literally a swiftness-of-thought writer (de Jaager, 1865; Donders, 1868). Experimenter and participant sat in front of a gramophone-like sound cone, to which a membrane was attached at its lower end, holding a needle to write the incoming focused sound waves to a band of sooted paper, wrapped around a rotating drum. The experimenter spoke the stimulus and the participant reacted vocally according to the experimental task. The time elapsed between stimulus onset and reaction onset was gained in a cumbersome manner by counting the number of cycles a tuning fork had scratched into the paper band parallel to the vocal record. First, Donders and de Jaager measured the physiological reaction time about 200 milliseconds and thus confirmed Hirsch's respective results. Then, they instructed the participant to react to one and only one stimulus from a randomly presented 5-element set of stimuli (namely the syllables *ka*, *ke*, *ki*, *ko*, *ku*) and in any other case to suppress the reaction. Finally, the participant had to react to every stimulus with its equivalent. Donders and de Jaager argued that the second task required stimulus discrimination in addition to the physiological reaction time, while the third task required discrimination effort *and* reaction choice effort in addition to the physiological reaction time. From these task-dependent reaction times they calculated the time slices for stimulus discrimination and reaction choice at about 40 milliseconds according to their so-called »subtraction method«.



Source Plan: Friedrich, 1883, p. 45; Geißler tube: Meyer's, 1893-97, 7th vol., p. 240; Telegraph key: Zimmerman, 1928, p. 123; Rühmkorff inductor: Meyer's, 1893-97, 9th vol., p. 224; Daniell element: Meyer's, 1893-97, 7th vol., p. 47; Chronoscope: see Fig. 1.

Fig. 2: Friedrich's experimental setup shown in the upper left corner, as depicted in Friedrich's (1883) report; one can also see some important components in 3D-view, this setup is built from. For a detailed explanation, see the text.

More or less immediately after Wundt had established the Leipzig institute in 1879, a young mathematician named Max Friedrich (1856-1887) began to measure reaction times to visual stimulation with the chronoscope (Friedrich, 1883). As his doctoral thesis that emerged from these experiments is commonly seen as the first dissertation in experimental psychology at all, Friedrich's setup will be explained in a little more detail by means of to the plan provided by Friedrich himself (see Fig. 2): The visual stimulus was placed on the rear side *O* of a darkened box *K*, and the participant was instructed to look through a small hole *o* into this box. At the moment of presentation the stimulus was lighted by a so-called Geißler tube[2] *G*, an ancestor of contemporary gas discharge tubes. A so-called Rühmkorff inductor[3] *R*, which transformed a low input voltage from a thermoelectric pile *Th* into a high output voltage, served as the high voltage source for the Geißler tube. Besides the high voltage circuit *J*, there was a low voltage circuit *N*, with a source in form of two so-called Daniell elements[4] *D*, accumulators in today's terminology. The low voltage circuit supplied the chronoscope *Ch* with electricity.[5]

A typical trial was executed as follows: the participant was positioned in front of the box and had to keep the telegraph key *U* pressed down. Now, the experimenter pressed the switch *V* to close the high voltage circuit and hereby to ignite the Geißler tube. Simultaneously, the chronoscope circuit was closed via the relay-like element, denoted by a question mark *?* (Friedrich did not explicitly explain this component), and the electric line *H*. Thus, stimulus presentation and starting the chronoscope were synchronized. The participant was instructed to react by releasing the key *U*. This action interrupted the high and low voltage circuit simultaneously. Thus, in the moment of releasing the key the tube went out and the chronoscope stopped with the elapsed time between stimulus presentation and the participant's reaction.

With this setup Friedrich again confirmed Hirsch's simple alias physiological reaction times at about 200 milliseconds. By utilizing Donders' and de Jaager's subtraction method, he determined the highly inter-individually as well as intra-individually varying recognition time for a color stimulus out of a 4-element set of stimuli in a range between 100 and 300 milliseconds. Furthermore, he found recognition times for 1-digit through 6-digit numbers, ranging from about 300 milliseconds for the 1-digit numbers to about 1.6 seconds for the 6-digit numbers, again highly varying between as well as within participants.

After the arrival of reaction time measurement at Wundt's institute, the field of application for chronometric investigations seemed nearly inexhaustible. Martin Friedrich Gottlob Trautscholdt (1883), for example, investigated the time expenditure of association processes, Ernst Tischer (1883) measured discrimination times for independently varied acoustic intensities, and Emil Kraepelin (1883a, b) investigated the influence of psychotropic drugs on reaction times.

2 named after the German physicist and inventor Heinrich Geißler (1814-1879)

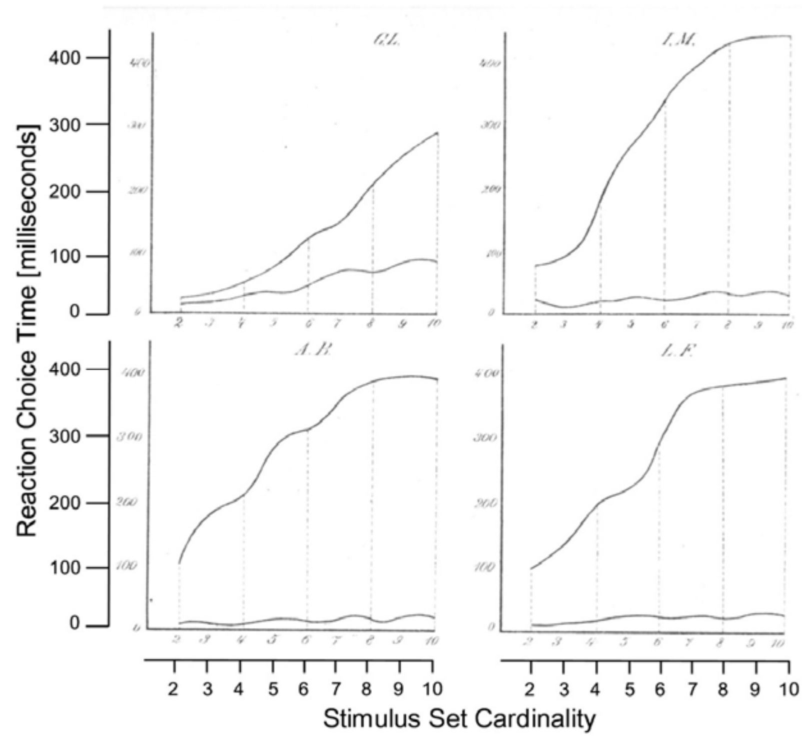
3 named after the German mechanic Heinrich Daniel Rühmkorff alias Ruhmkorff (1803-1877)

4 named after the English chemist John Frederic Daniell (1790-1845)

5 Via the rheostat *Rh* the amperage in this chronoscope circuit was adjustable to calibrate the time measuring device. The respective amperage in this circuit could be seen on an amperemeter, *Gs*, they called galvanoscope in the 19th century.

Julius Merkel (1885) earned his doctorate at Wundt's institute in the mid-1880s with a study on reaction times to visual stimulation too, using a similar setup as Friedrich. Again, the exposition unit was a darkened box, in which the stimulus was exposed under instantaneous lighting. With this setup Merkel determined, amongst others, the choice time of an adequate reaction to a stimulus out of a set of stimuli of cardinality 2 through 10. The stimuli were the first five Arabian and the first five Roman numbers. The participant was instructed to react to the 2 through 10 different stimuli with 2 through 10 different fingers via the so-called »psychophysical piano«, an arrangement of two multiple telegraph keys (see Fig. 3a).

Source: Photograph from the Wundt room at the University of Leipzig. © 2008 Maximilian Wontorra



Source: Source: Merkel, 1885, Appendix, Table I, clipped from Fig. 3. Axes re-labeled by © 2008 Maximilian Wontorra

Fig. 3a, b: The »psychophysical piano«, constructed to take up the participant's stimulus-adequate reaction to a randomly presented stimulus from a set of stimuli (a). Merkel's (1885) reaction choice times in milliseconds (ordinate) plotted against the stimulus set cardinality (abscissa) for four exemplarily selected participants (b).

Fig. 3b (previous page) shows Merkel's findings of four participants' reaction choice times plotted in milliseconds as a function of stimulus set cardinality (G. L. = Gustav Lorenz, I. [J.] M. = Julius Merkel himself [?], the others are not assignable). From these plots one can see that choice times do not increase linearly with the number of available stimuli, but that the times needed to identify a target stimulus are curvilinear-convex functions of the number of available stimuli. With this result Merkel anticipated in some respects William Edmund Hick's (1912-1974) Law[6] by more than 60 years, at least qualitatively.

After six or seven years of reaction time studies at the Leipzig institute this initially so promising research attempt ran into problems mainly in the course of the investigations by Wundt's doctoral students James McKeen Cattell and Gustav Oskar Berger who determined time expenditures for discrimination operations close to, in some cases even *lesser than* (!) zero (see Berger, 1886; Cattell, 1886a, b, c, 1888; see also Cattell, 1886-87; Wontorra, 2008, pp. 101-120). After these disquieting results a theoretical reorientation took place. Leipzig researchers bit by bit abandoned Wundt's up to then almost dogmatically restated strictly serial approach of information processing in favor of a new view, thinking of mental operations as overlapping in time (cf. e. g., Lange, L., 1888).

Attempts to quantify the phenomena of consciousness

As the concept of consciousness was one of the salient characteristics of Wundt's psychology, another important research line at Wundt's institute was concerned with the phenomena of consciousness and their quantification. According to Wundt's view, consciousness was the total content of our immediate experience (cf. e. g. Wundt, 1908-11, 3rd vol., p. 296). Wundt's consciousness consisted of an inner visual field and an inner visual focus. The entry of a single idea from the field to the focus was named »apperception« in the terminology of the 19th century[7]. What Wundt and his contemporaries called apperception can be called today, more or less synonymously, attention, and what they called »apperceptual focus« comes closest to the concept of short-term or working memory in current terminology.

Working memory capacities. One important issue concerned the question of how many single ideas can be held simultaneously in the mentioned focus. The obvious method to answer this question was to

6 Hick's (1952) Law says that the search time for a target in a set of stimuli equals the dyadic logarithm of the cardinality of this respective set. This can be interpreted in that way, that we do not scan the set in question serially, but that we walk down a binary search tree, so to speak graph-theoretically.

7 referring to a concept which can be traced back to Gottfried Wilhelm Leibniz (1646-1716)

increase a set of stimuli in respect to its cardinality and expose this set tachistoscopically[8] as long as the participant was no longer able to replicate the single items from this set.

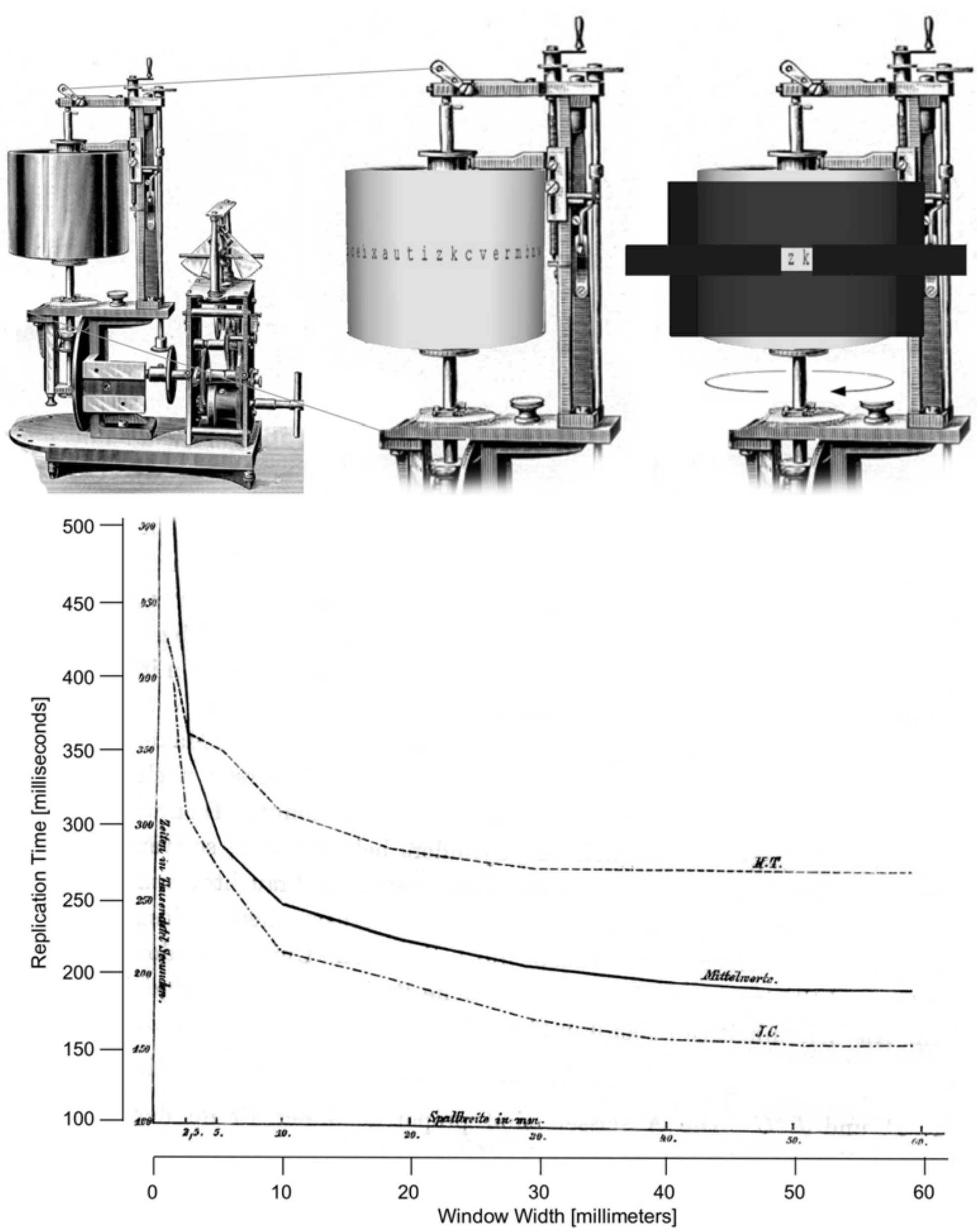
In 1885, aforementioned James McKeen Cattell (1860-1944) from Easton, PA, USA, published the first of a longer series of investigations in Wundt's journal *Philosophische Studien* [Philosophical Studies]. Like other researchers in the realm of mental chronometry, in this study as in his following ones, which were combined in 1886 in a dissertation entitled *Psychometrische Untersuchungen* [Psychometric investigations], Cattell was primarily interested in the determination of the exact time expenditure of single mental operations. But in the study from 1885, entitled *Ueber die Zeit der Erkennung und Benennung von Schriftzeichen, Bildern und Farben* [On the time needed for the recognition and naming of characters, pictures, and colors], he also found, more or less incidentally, an only slightly inter-individually varying – in current terminology – buffer size of working memory. This investigation is worth mentioning for at least one more reason, namely that it is hardly to be surpassed in the simplicity of its experimental setup, as well as its rationale. In this respect, it contrasts pleasantly with some other investigations at Wundt's institute from the 1880s, where the technical effort was not always immediately paralleled by the complexity of the question to be answered. Cattell justified his simple setup in the introduction to his study. He argued that the complex setups used so far had to be adjusted and maintained in a difficult and time-consuming manner, that the exposition units only rarely produced the stimulus to a satisfactory quality[9], that the chronoscope did not measure times exactly enough[10], and that the participants' task was artificial and thus far removed from everyday tasks, which would increase the risk that in some cases *not the total* time effort and in other cases *more than* the time effort of the mental operation in question was determined (see Cattell, 1885, p. 635). Surely, these methodological objections were justified. This makes it all the more astonishing that, during his series of investigations, Cattell's

8 Tachistoscopes were devices designed for the short-term presentation of visual stimulus arrangements. In tachistoscopes a blind with a window in it was moved in front of the mentioned arrangement. For the time of the window's passage, the arrangement was short-term exposed to the participant.

9 Needless to say that the sudden change of luminance, associated with the method of instantaneously lighting the stimulus in a darkened box, forced the beholder's eye to an adaptive task, taking time in its own right so that the time taken by the mental act in question seemed to be longer than it was in fact.

10 The Hipp-type chronoscope was a 19th-century state-of-the-art chronometer, but it had to be calibrated very exactly. Moreover, it had to be checked during the experimental sessions rotationally, and it had to be protected against permanent magnetization of the iron kernels of its coils by changing the direction of the direct current betimes. This was not absolutely guaranteed at least during the early years at Wundt's institute. Thus, the chronoscopically measured times of the early Leipzig investigations could not be trusted in unconditionally (cf. Wontorra, 2008, p. 65ff.).

setups grew similarly complex as those of his time measuring predecessors. However, this matter is of no relevance to the study to be discussed here.



Source: Zimmermann, 1928, p. 185; post-processed by © 2009 Maximilian Wontorra

Source: Cattell, 1885, p. 638. Axes re-labeled by © 2009 Maximilian Wontorra

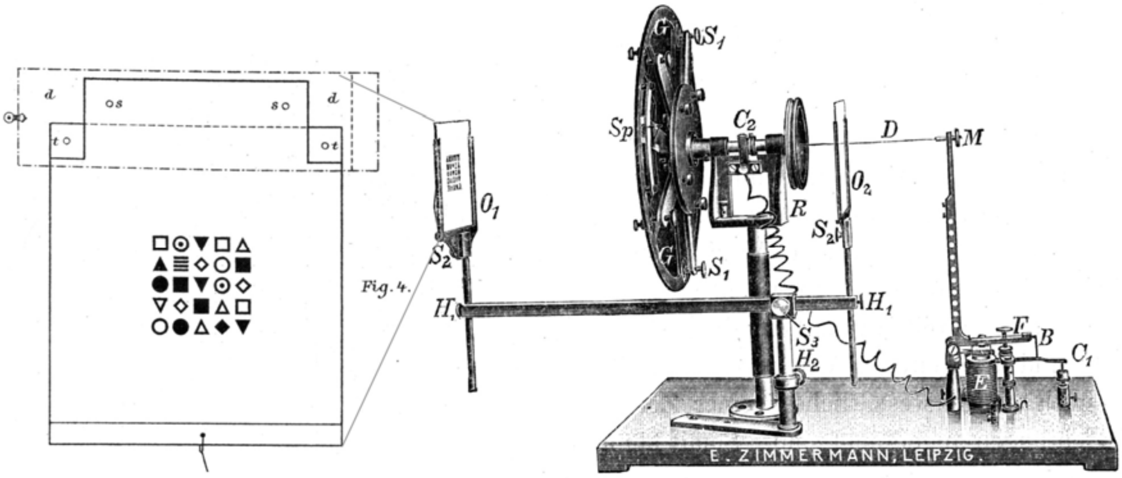
Fig. 4a, b: Cattell's (1885) experimental setup to determine the time taken by the recognition and vocalization (in short: replication) of characters (a); plots of the replication time of a single character as a function of the number of simultaneously visible characters (b). For a detailed explanation, see the text

To determine the time taken by the recognition and vocalization of characters (in short: the replication time), Cattell »misused« a recording instrument known as kymograph (see Fig. 4a) for his experiments. As is well-known, the kymograph was a clockwork-driven drum, on which 19th-century experimental physiologists recorded time series of physiological magnitudes such as respiration parameters, pulse rate, and so forth. The kymograph drum with a diameter of 50 centimeters was covered by Cattell with a band of white paper showing a random series of characters, as depicted above. Finally, Cattell placed a blind with a window, 1 centimeter in height and of variable width, in front of the drum. The height of the characters and the spacing were chosen so that for a width of x centimeters, x characters were visible simultaneously. If the width was less than 1 centimeter, only one character moved through the participant’s visual field at a time. This was followed by a short pause, with the next character then appearing and vanishing again. With the participant positioned in front of the drum in such a way that he or she could comfortably see the single character or a subset of the total available characters in the window, Cattell slowly started the drum’s rotation clockwise to increase the angle velocity of the drum. This kept being increased bit by bit, until the participant was overtaxed and no longer able to properly replicate the 30 or 40 characters moving through his or her visual field.

Cattell varied the window width independently and determined for each particular width the respective limit velocity. From the window width and the limit velocity he then calculated the (mean) time taken to replicate *one single* character as a function of window width. Cattell was vague in his explanation of this calculation, but it is to be assumed that he considered the replication time of a single character to be the time needed for moving forward the visible subset of letters by exactly one element.

Fig. 4b (previous page) shows plots of the replication times for the participants H. T. and J. C. (probably James McKeen Cattell himself) as a function of window width (dashed lines) and it shows the respective course of the means (solid line), averaged over the – in total – nine participants. One can see that the replication time decreases with window width, but beyond a width of 40 millimeters, i.e. four simultaneously visible characters, practically no further time gain is observable. In other investigations, not published until 1886, Cattell had determined the recognition time and the vocalization time for a single character in daylight conditions at about 250 and 100 milliseconds, respectively. By using a self-constructed device, which he called »Fallchronometer« [fall or gravity chronometer], he was able to stimulate tachistoscopically and to measure exposition times. Therefore, Cattell argued, it is not a big surprise that replication times at a window width of 10 millimeters, i.e. exactly one visible character at a given moment, equaled fairly accurate 250 milliseconds. As in this case both recognition and vocalization were completely automated processes, the respective previous character could be vocalized, while the respective next character was apperceived. In the case of two or more simultaneously visible characters, the process of vocalization and the several processes of apperception were overlapping up to the boundary value of about four simultaneously visible elements. According to Cattell’s interpretation, with four elements the maximum of simultaneously processable impressions was reached. Thus, a numerical value was identified by Cattell as a real capacitive limitation of our mental machinery that corresponds astonishingly well to the *Magical number 4* of recent findings (cf. Cowan, 2001, 2005) and which seems to be even a better estimate of the real limitation of short-term memory than George A. Miller´s (1956) famous *Magical number 7, plus or minus 2*.

Awareness of ideas. To complicate things, in Wundt's psychology the question of the number of momentarily present ideas was not an all-or-none problem, but each and every idea present at a given moment had moreover a certain degree of awareness (or clearness).

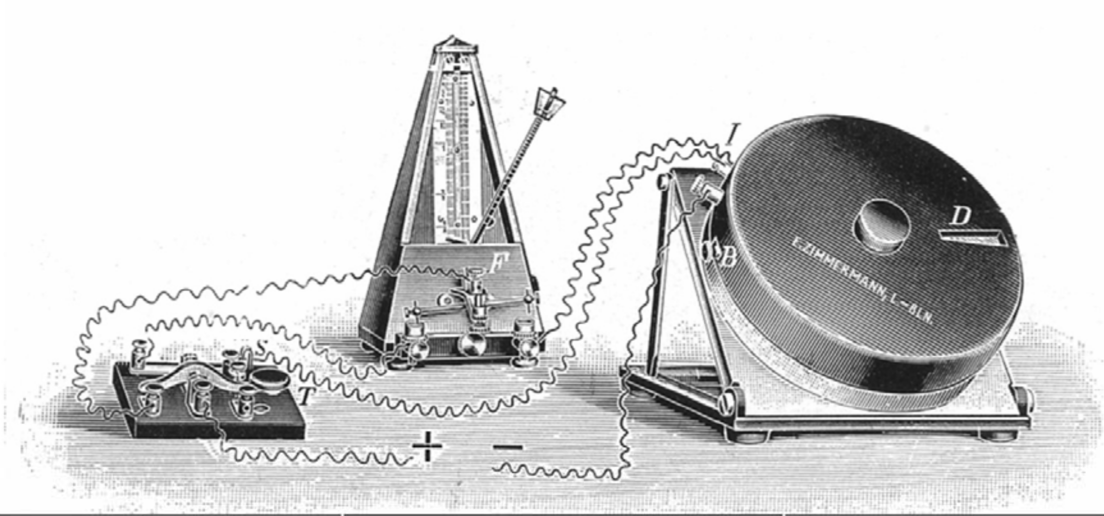


Source: Wirth, 1902, Appendix, Table II, Fig. 4 and Wirth, 1903, p. 688, respectively

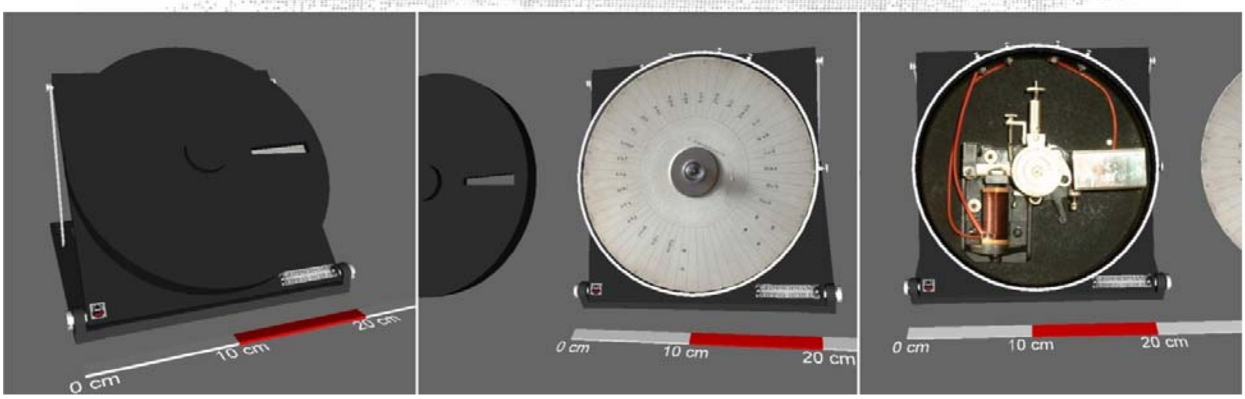
Fig. 5: Wirth's mirror tachistoscope (right side) with a magnification of the stimulus array O_1 (left side). For a detailed explanation, please see the text.

Consequently, Wilhelm Wirth (1876-1952), since 1908 the co-director of the Leipzig institute, designed an apparatus he called »Spiegeltachistoskop« [mirror tachistoscope] (see Fig. 5, right part) at the turn of the century. This apparatus allowed a short-term modification of single elements in a permanent stimulus array, as illustrated in the left part of Fig. 5, which shows the magnified element O_1 from the tachistoscope construction. By a slight modification of single elements, as, for example, the omission of the center of one of the depicted circles, and the detection probability for these changes by the participant in short-term presentation, Wirth (1902, 1903) wanted to determine the awareness of the respective element. The participant sat to the left of a rotating mirror *Sp*, looked into it and thus permanently saw the mirror image of the original stimulus array O_1. The experimenter sat on the right (behind the construction). By pulling the cable *D* the experimenter opened a window in the rotating mirror, so that the participant could have a short glance at the modification O_2 every time the gap in the mirror passed the participant's line of sight. Needless to say, that the original and the modification had to be positioned in such a way that they stayed congruent over time except for the experimentally varied changes.

»Volatility« of the contents of consciousness. Of course, the number of momentarily present contents of consciousness as well as the degree of awareness of a single content is only a snapshot. At the latest when Hermann Ebbinghaus (1850-1909) had published his seminal studies on memory contents and their time-dependent »dissolution processes«[11] in 1885, one had to be interested in the time characteristics of these volatile contents of consciousness (Ebbinghaus, 1885).



Source: Zimmermann, 1928, p. 64



Source: Screenshots of a virtualized Ranschburg-type mnemometer. © 2003 – 2009 Maximilian Wontorra

Fig. 6 a, b: A simple setup for the standardized presentation of stimuli in memory investigations (a, upper part); three screenshots of a virtualized Ranschburg-type mnemometer, a widely used device in memory investigations (lower part, b). For detailed explanation, see the text.

Fig. 6a (upper part) depicts a simple setup for the standardized presentation of item series in learning and retrieval experiments. The setup consists of a simple telegraph key, a metronome, equipped with an interrupting mechanism, and a so-called »mnemometer« (literally a memory meter), constructed by Pál Ranschburg (1870-1945), who was a pioneer in Hungarian psychology. All these components are

11 It has to be noted, that already before Ebbinghaus the American physicist Francis E. Nipher (1847-1926) investigated memory processes, but he used numbers in contrast to Ebbinghaus who experimented, as is commonly known, with senseless syllables (cf. Nipher, 1876, 1878).

integrated into an electrical circuit. Reaching its maximum deflection, the oscillating metronome briefly closed the electrical circuit, and this impulse caused the stimulus change in the mnemometer (assuming the setup was activated by the experimenter via the telegraph key). Fig. 6b (lower part) consists of some screenshots of a virtualized Ranschburg-type mnemometer. The left shot shows the still closed device. The center shot shows the stimulus card after removal of the apparatus' lid, while the right shot allows a view into the device's innermost card-holding mechanism that consisted in a locked axis under spring tension, which was for the time of the electrical impulse (temporarily) unlocked by an electromagnet and thus enabled to rotate the stimulus card by one step to present the next stimulus in the lid's window.

Psychophysics of time perception. Based on Ernst Heinrich Weber's (1795-1878) investigations from the first half of the 19th century, resulting in Weber's constant ratio of – on the one hand – the stimulus *S*, and – on the other hand – the increment on this stimulus, necessary to produce a just noticeable perceptual difference, in short: $\frac{\Delta S}{S} = const.$, Gustav Theodor Fechner (1801-1887) opened a new field of research with his *Elements of psychophysics* (1860). As is well-known, psychophysics is concerned with finding functions, mapping *physical* to *perceived* intensities. As Weber and Fechner were important predecessors of Wundt at the University of Leipzig in establishing empirical methods in psychology, it was in a sense straightforward for Wundt and his co-workers to conduct experiments in the realm of psychophysics, too. Mainly inspired by the experiments conducted by Ernst Mach (1838-1916) and Karl von Vierordt (1818-1884) (see Vierordt, 1868), the experiments at Wundt's institute focused on the investigation of the »Zeitsinn« [time sense], as they called the psychophysics of time perception in late 19th century.

At Wundt's institute, researchers predominantly studied the psychophysics of time perception in the auditory modality. The first Leipzig investigation in this field was conducted by Julius Kollert (1883). Kollert who was convinced to have detected methodological weaknesses in Mach's und Vierordt's experiments, used two metronomes, like his criticized predecessors; the first metronome ticked a standard time interval, while the second ticked a target interval in the participant's back. These intervals were separated by a short time span. The standard interval's length was varied independently, and – starting with a target interval equaling the standard interval's length – the experimenter varied the length of the target interval according to Fechner's so-called »method of minimal changes« as long as the participant perceived both interval lengths as equal. By pooling data over the participants, plotting the target-standard differences Δ against the standards t and finally determining a best-fit curve according to the methods of least squares, Kollert found this exponential psychophysical function $\Delta = a - be^{t}$. Here, e is the Euler number and a, b are parameters, fitted by Kollert to his sample as $a = 0.1021$ and $b = 0.0480$. With these parameters, Kollert's connection between the – as it was initially called by Wundt and colleagues – »estimation error«, *Δ*, and the physical length of an interval, *t*, was a smooth, monotonically decreasing function. Short physical intervals were subjectively over-, and long intervals were under-estimated, with a point of indifference at a physical length of about 0.75 seconds. Kollert's exponential function was at least implausible in respect to the fact that with growing physical lengths, the discrepancies between the objective lengths and the perceived ones would rapidly approach negative infinity.

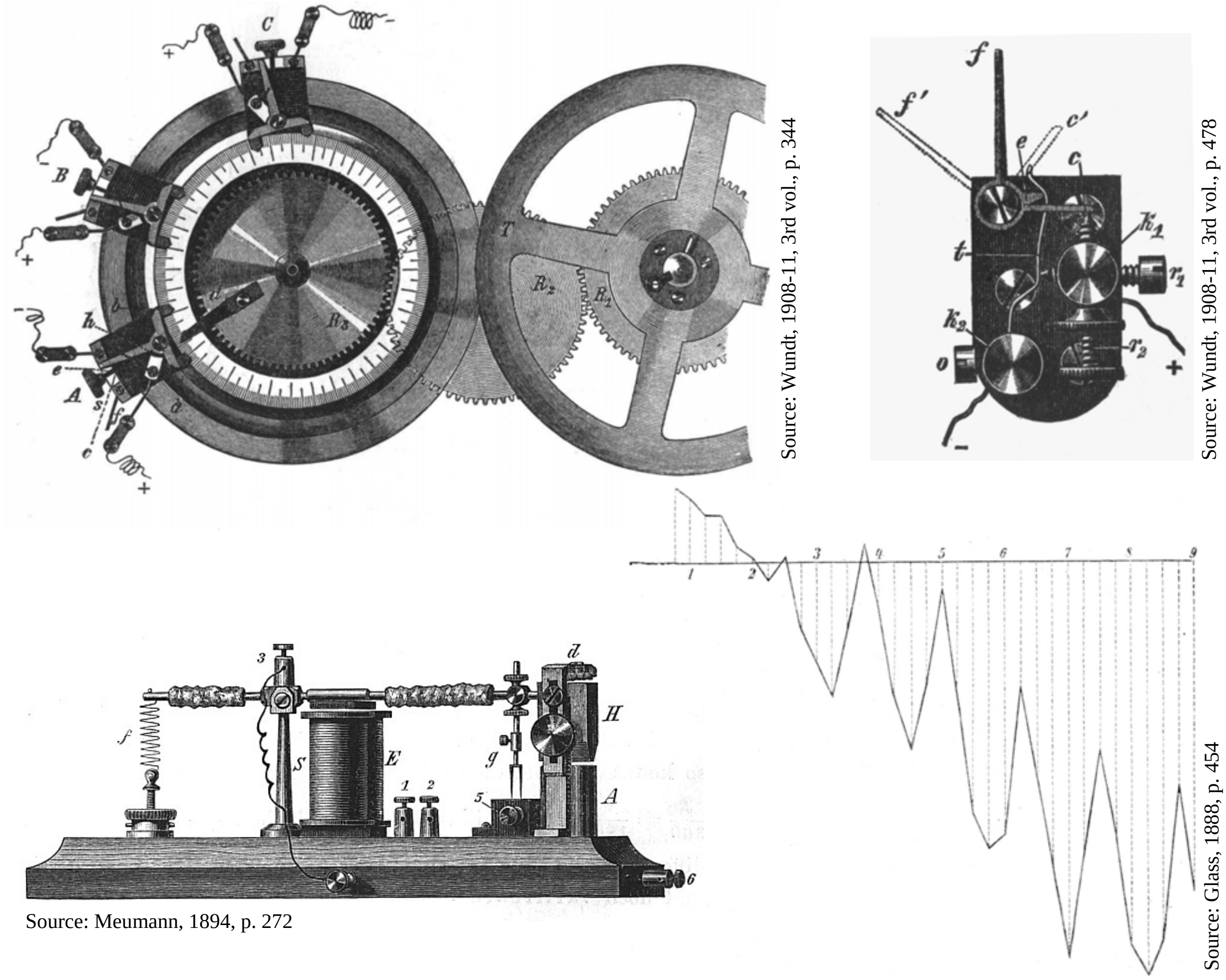


Fig. 7a, b, c, d: A so-called time sense apparatus (upper left, a); a switch as it was attached to the static periphery of the time sense apparatus (upper right, b); an electro-magnetically triggered sound hammer (lower left, c); a function plot of Glass's (1888) so-called »constant error« (as the discrepancy between perceived and physical lengths of time intervals) against the physical length of a time interval (lower right, d). For a detailed explanation, see the text.

Mainly in order not to be restricted to relatively short intervals realizable by means of metronomes, Kollert's successors in the realm of time sense investigations experimented with a new stimulus generator, they called »Zeitsinnapparat« [time sense apparatus], as depicted in sub-Fig. 7a (upper left).

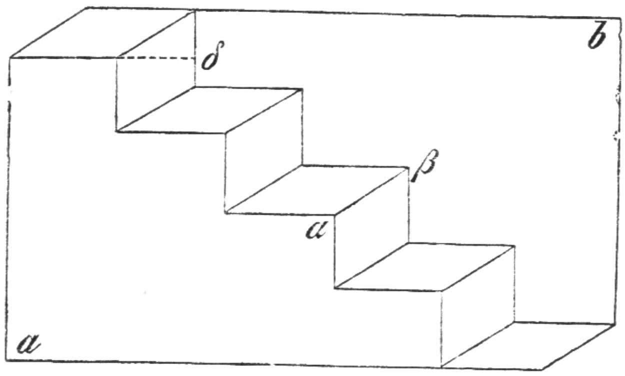
This Meumann-type[12] apparatus consisted in a gear-driven rotating disc, to which a pin was attached. As the disc rotated, the pin touched switches, similar to that depicted in the sub-Fig. 7b (upper right). These switches were mounted onto the static peripheral ring of the time sense apparatus. As soon as one of these switches was touched by the pin, an electrical circuit was closed which in turn triggered a beat of an electro-magnetic sound hammer, as it can be seen in sub-Fig. 7c (lower left). With three of the mentioned switches, two intervals were realizable. In this case, the center switch and the corresponding sound hammer beat marked the end of the standard and the beginning of the target interval, respectively. By means of this apparatus several investigations were conducted at Wundt's institute, each one criticizing the previous investigation in respect to its methodological weaknesses. In 1887, Paul Richard Glass submitted his time sense investigation at Wundt's institute as a doctoral thesis (cf. Glass, 1888). Sub-Fig. 7d (lower right) shows his function, again plotting the now misleadingly so-called »constant error« as the target-standard difference (ordinate) against physical time spans in seconds (abscissa), with a y-axis, ten times over-scaled in comparison to the x-axis. Glass's psychophysical function exhibits a linearly decreasing trend and a superimposed oscillatory component with a frequency of about 1 Hz. Despite all divergences in detail, all of Kollert's successors found this linear trend with a point of indifference (the function's root) between 2 and 3 seconds, which is close to that value found in current investigations on the duration of the psychological present (cf. e.g., Pöppel, 2004). Moreover, all researchers found this peculiar oscillatory component.

Apperceptual waves. Mainly inspired by investigations conducted by the otologist Viktor Urbantschitsch (1847-1921) at Vienna (Austria) in the realm of auditory perception, in the second half of the 1880s, investigators at the Leipzig institute started to develop an interest in a phenomenon that can be traced back to even David Hume (1711-1776) and his *Treatise of human nature* (Hume, 1740). Wundt and his colleagues called this phenomenon »Apperzeptionswellen« [apperceptual or attentional waves]. It consisted in the fact that a stimulus (of low intensity) intermittently fades out to be re-perceived clearly after a certain time span. Hopefully, to have a post-hoc explanation for the periodicities in the just mentioned psychophysical functions of time perception, Leipzig researchers started to investigate this phenomenon in the auditory, the visual, as well as the tactile modality.

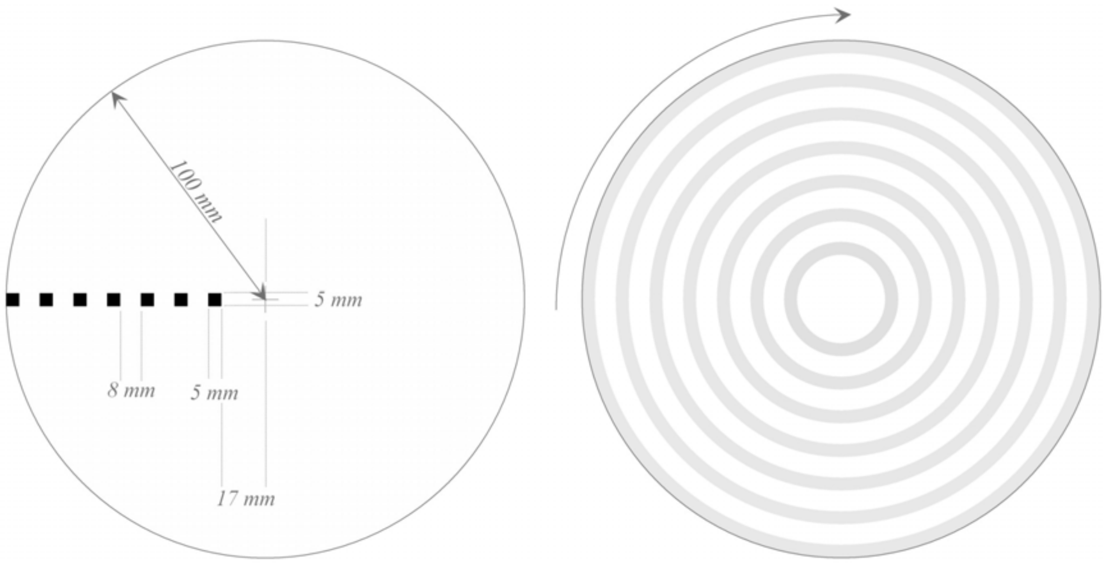
The first extensive Leipzig investigation of these apperceptual waves was conducted by Nicolai Lange from St. Petersburg (Russia). N. Lange (1888) used tactile, auditory, and visual stimuli to determine primarily the chronoscopically measured time spans between the moments of maximal perceived

12 named after Ernst Meumann (1862-1915), one of Wundt's assistants and lifelong friends, who essentially enhanced previous models of this apparatus; for Meumann's own investigations see Meumann (1893, 1894).

clearness of the respective stimulus (The participant had to start or stop the chronoscope by pressing or releasing a telegraph key, respectively.) For the visual modality Lange used, among other stimuli, an ambiguous figure, called »Schrödersche Treppe« [Schröder staircase][13], as depicted in sub-Fig. 8a. (The Schröder staircase is besides e. g. the »Necker cube«, »Rubin's vase«, or the »Spinning dancer«[14] one of a multitude of ambiguous figures, giving rise to two different perceptions.) In the case of Schröder's figure, one either sees a staircase from underneath (concave) or from above (convex) and, upon continuous viewing, the impression alternates. Using the Schröder staircase, Lange determined the time spans during which the convex or the concave version of the staircase was visible.



Source: Lange, N., 1888, S. 406



Source: Drawing of »Masson's disc«, as described and used by Pace (1893). © 2008 – 2009 Maximilian Wontorra

Fig. 8a, b: The Schröder staircase (a), an ambiguous figure, as used by N. Lange (1888); Masson's disc (b), as described and used by Pace (1893). For a detailed explanation, see the text.

The general Leipzig view, according to which the reason for the apperceptual waves was primarily an attentional one, was not undisputed. Amongst others, for Wundt's former doctoral student and later on professor at Harvard, Hugo Münsterberg (1863-1916), as well as Alfred Lehmann (1858-1921), who was

13 named after Heinrich Georg Friedrich Schröder (1810-1885) who described this figure in 1858 for the first time

14 see, for example, http://en.wikipedia.org/wiki/The_Spinning_Dancer [Nov 29, 2009]

for a research stay at Leipzig in the mid-1880s, these waves were quite simply due to a temporary fatigue of the respective sense organ.

After having determined the periodicities of each of the diverse modalities separately Lange tried to conduct, so to speak, an *experimentum crucis* to decide, whether the central-attentional or the peripheral-adaptive explanation for the apperceptual waves was appropriate. To accomplish this, Lange stimulated the visual and the auditory channel simultaneously. The participant was instructed to press two buttons, one button to signal the moments of maximal clearness on the first, the other to signal the respective moment on the second sensory channel. In this case, the participant's reactions were recorded kymographically. Finding roughly the same periodicities of fluctuation in this combined experiment as he had found in the previous single-modality investigations, it was sufficient evidence for Lange to express his conviction that the phenomenon of apperceptual waves was due to periodical central shifts of attention, solely.

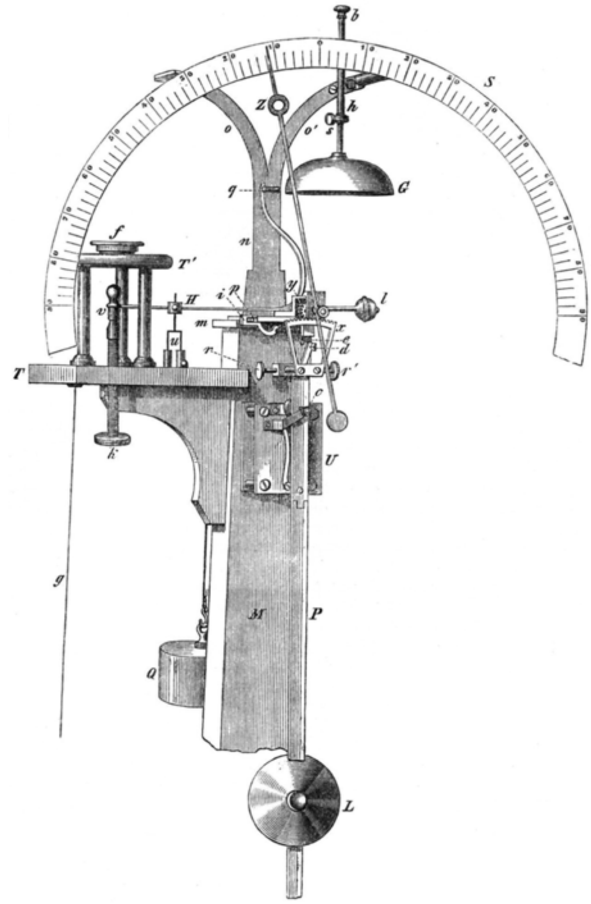
To gather additional evidence against the peripheral explanation, another former doctoral student at the Leipzig institute, Edward A. Pace (1861-1938), conducted experiments with a device named »Masson's disc[15]«, as shown in sub-Fig 8b, previous page (Pace, 1892). While rotating this disc with a sufficiently high velocity, the beholder sees a number of grey rings, decreasing in luminance with the distance to the disc's center. Arbitrarily assigning a luminance of value 1 to the background of Masson's disc, Helmholtz (1867) calculated the luminance *h* of a specific ring according to the formula $h = 1 - \frac{d}{2r\pi}$, with π, r, and d being Ludolph's number, the disc's radius, and the distance between the center of the respective ring-generating black patch and the midpoint of Masson's disc, respectively. The participant's task was to gaze at one of the outer rings and to report the perceptual fluctuations of the ring gazed at. In a subseries of experiments Pace worked with participants whose eyes were atropinized. As even these participants reported the respective fluctuations, Pace argued that the putative temporary fatigue of the eye's adaptive system of muscles was not a sufficient explanation of the phenomenon.

To this day, researchers do not exactly know how to explain the bi-stable percepts associated with ambiguous figures (cf. Kornmeier, 2007). Utilizing event-related potentials as e. g. EEG records, they try to find out whether bottom-up (mainly physiological) or top-down (mainly psychological) processes are responsible for those percept changes. Most recently, those tiny oscillations of the eyes' axes, the so-called microsaccades, which have been considered as pure noise of the visual system for a long time, have

15 named after Antoine Philibert Masson (1806-1858 or 1860)

returned to the focus of interest as indicators of an impending attentional shift. In eye-tracker studies, stimulating amongst others by means of »Troxler's figure«[16], researchers found that the frequency of microsaccades increased some milliseconds prior to the re-appearance of the stimulus (cf. Engbert & Kliegl, 2003; Hafed & Clark, 2002; Martinez-Conde et al., 2004, 2006; Martinez-Conde & Macknik, 2007).

Processing multimodal stimuli. Investigations in the characteristics of processing disparate sensations were, in the end, just as the research line of reaction time studies, inspired by those astronomical problems, mentioned at the beginning of this article. Wundt had been interested in this topic from an early point in time, and he already published an article on it in the family magazine *Gartenlaube* [Arbor] in 1862. In this article he introduced a method for the determination of the »swiftest thought« by means of a slightly modified standard pendulum clock (Wundt, 1862). For that, he attached two clappers to the pendulum rod, each of which hit a bell at the moment the pendulum reached its maximum deflection to the left or the right, respectively. Comparing the *de facto* position of the clock's second hand to the *perceived* position at the moment of the bell tone, he found a divergence of about eight tenth of a second. He interpreted this elapsed time to be his personal swiftest thought, for Wundt was convinced that the processing of the auditory stimulus distracted the attention from the visual impression for the mentioned time span. An enhancement of this rough-and-ready device was Wundt's »Complicationspendel« [complication pendulum], as depicted in Fig. 9. In principle, this apparatus consisted of a hand *Z* that was moved by a pendulum *P* in front of a semicircular scale *S*. By shifting the weight *L* along the rod *P*, the pendulum's period was adjustable in a range between 0.5 and 1.0 Hz. At any point on the hand's



Source: Wundt, 1908-11, 3rd vol., p. 72

Fig. 9: Wundt's »Complicationspendel« [complication pendulum]. For a detailed explanation, see the text.

16 named after Ignaz Paul Vitalis Troxler (1780-1866); this figure consists of a light grey ring with a fixation cross in its center. Gazing at the cross, the ring intermittently disappears.

trajectory a distracting auditory stimulus could be triggered by beating the clapper *q* against the bell *G*. By only slightly modifying the apparatus a tactile distractor in form of an electric shock was applicable, too.

The first to conduct an extensive investigation on the processing of disparate stimuli (or »complications«, as the late 19th century called multimodal processing) by means of Wundt's pendulum, was Woldemar von Tchisch, a physician from St. Petersburg (Russia) who experimented at the Leipzig institute in the 1880s (von Tchisch, 1885). Von Tchisch independently varied combinations of tactile and/or auditory distractors as well as the hand's position at which the distracting stimuli were triggered. With himself being his one and only participant in his experiments, von Tchisch produced huge data sets. One of the results gained from the data was that distractor-caused time shifts in perceiving the hand's position was the greater, the lesser the pendulum's (and thus the hand's) velocity was. This is a highly contra-intuitive result. Assuming that it takes a certain amount of time to move one's attentional focus from the (visual) main sensation to the distracting sensation and back again to the main sensation (the central idea behind all those investigations concerned with figuring out the time characteristics of attentional shifts), one would expect the divergence between the hand's de facto position and the perceived one to be the smaller, the smaller the moving object's velocity was during this »blackout phase« of attentional shifts. Similar to this result, nearly all of von Tchisch's results massively lacked of credibility. This may be due to constructional weaknesses of the stimulus generator. To circumvent these problems, Leipzig researchers developed variations of Wundt's original pendulum (Weyer, 1898, 1900) or they experimented with a new clock-like construction called complication clock (Geiger, 1903). In this latter device a weight-driven hand rotated at constant angle velocity in front of a clock face.

The last to experiment with Wundt's original pendulum was Christof D. Pflaum at the end of the 19th century (Pflaum, 1900). Caroline Augusta Foley Rhys Davids (1857-1942) wrote a review of Pflaum's experiment in *Mind* (Rhys Davids, 1899), saying, in essence, that Pflaum forgot to report a serious problem associated with this device, consisting in the fact that the device's hand would always jump at the moment of triggering the distractor. Thereupon, Wundt (1900) wrote a huffish reply, accusing all those who unsuccessfully had tried to replicate the (mistrusted) Leipzig results by means of his pendulum to be incapable of handling this apparatus properly.

Summary

As the author hopes, this short sketch made clear that researchers in early apparatus-based experimental psychology investigated a series of topics that are still relevant for today's psychology. After a long developmental history of methods and technology, contemporary researchers go for new results with enhanced methodological repertory and updated devices, of course.

The perhaps most important result regarding early reaction time studies was the fact that, after a couple of years, Leipzig experimenters were convinced that they had gathered sufficient evidence against Wundt's approach of strictly serial information processing. This caused a new view similar to contemporary theories of information processing according to which particular mental operations take place simultaneously and are therefore under-summative in respect of the total amount of time consumed by each of the operations individually.

Within the group of consciousness studies, the investigations on the processing of multimodal stimuli did not produce any reliable results. This is mainly due to the exposition units for the visual main stimulus and the distracting tactile/auditory stimuli, as these units suffered from constructional defects that could not be overcome in Wundt's era. Trying to find the causes of the so-called apperceptual waves, Leipzig researchers did not succeed. This is not all too surprising, as even contemporary researchers do not exactly know how to explain the perceptual fluctuations associated with ambiguous stimuli. Despite all differences in individual function plots, in the realm of psychophysics of time perception Wundt and his colleagues consistently found that lengths of short time spans were subjectively over-estimated, while long spans were under-estimated. Moreover, in these experiments they found a point of indifference which is close to that value that was obtained in current investigations on the duration of the psychological present. All in all, the early attempts to determine working memory limitations were the most convincing ones. Using a really simple setup, already in the mid-1880s Cattell found values replicable in essence until today.

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