In Pursuit of Precision: The Calibration of Minds and Machines in Late Nineteenth-century Psychology

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The Calibration of Minds and Machines in Late Nineteenth-century Psychology

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Summary

A prominent feature of late nineteenth-century psychology was its intense preoccupation with precision. Precision was at once an ideal and an argument: the quest for precision helped psychology to establish its status as a mature science, sharing a characteristic concern with the natural sciences. We will analyse how psychologists set out to produce precision in 'mental chronometry', the measurement of the duration of psychological processes. In his Leipzig laboratory, Wundt inaugurated an elaborate research programme on mental chronometry. We will look at the problem of calibration of experimental apparatus and will describe the intricate material, literary, and social technologies involved in the manufacture of precision. First, we shall discuss some of the technical problems involved in the measurement of ever shorter time-spans. Next, the Cattell–Berger experiments will help us to argue against the received view that all the precision went into the hardware, and practically none into the social organization of experimentation. Experimenters made deliberate efforts to bring themselves and their subjects under a regime of control and calibration similar to that which reigned over the experimental machinery. In Leipzig psychology, the particular blend of material and social technology resulted in a specific object of study: the generalized mind. We will then show that the distribution of precision in experimental psychology outside Leipzig demanded a concerted effort of instruments, texts, and people. It will appear that the forceful attempts to produce precision and uniformity had some rather paradoxical consequences.

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[1] An earlier version of this article has appeared in Dutch: R. Benschop and D. Draaisma, 'Omwille van de Precisie', *Feit & Fictie*, III/4 (1997–8), 69–89.

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> It continues to rain, while the barometer with most shameless assurance continues to mark 'Schönes Wetter'. My room numbers amongst its attractions the said hopeful barometer. (Cattell in Sokal 1981, 129)[2]

1. Introduction

That measurements have to be exact and observations as accurate as possible, that instruments are better as they register ever smaller differences and yield outcomes on increasingly fine scales, that results should be reported as minutely as possible—all of this is second nature to present-day scientists. Precision is hardly felt as a demand at all; it has gained the status of an evident value. Scientific work is done—with the voluntary obedience characteristic of internalized ideals—as precisely as possible.

Precision has assumed the transparency of the obvious. So omnipresent is the culture of the smallest decimal that precision as a historical notion, as a value with its own particular past, has become virtually invisible.[3] The risk implied in this is that one may forget that precision did not always have an intrinsic value. Precision was developed for specific reasons in a process moulded by a wide variety of factors. This process was certainly not like the steady, linear shift of the decimal sign to the left; on the contrary, in each science it had its own course and pace, with sudden accelerations, delays, and stagnations.[4]

We shall present a case study on the construction and distribution of precision in late nineteenth-century experimental psychology.[5] In the psychological laboratory founded by Wundt (Leipzig, 1879), the first of its kind in the world, a veritable cult of precision emerged, in particular in the area of the measurement of reaction times to sensory stimuli. This experimental programme is now known as 'mental chronometry'. Within the context of this programme Wundt and his collaborators articulated standards of precision, both by means of an impressive armamentarium of instruments and by imposing strict rules on the social organization of experiments. Experimenters and subjects observed a code of behaviour that sometimes reached beyond the temporal and spatial limits of the experiment itself.

[2] *An Education in Psychology; James McKeen Cattell's Journal and Letters from Germany and England 1880–1888*, edited by M. M. Sokal (Cambridge, MA, 1981).

[3] Compare B. J. Hunt, 'The Ohm is Where the Art Is: British Telegraph Engineers and the Development of Electrical Standards', *Osiris* (Special Issue on Instruments) edited by A. van Helden and T. L. Hankins, 9 (1994), 48–63 (p. 48).

[4] The construction of precision is at issue in several historical studies. Two important books are the following: A recent collection of case studies edited by M. N. Wise traces the development of precision during the nineteenth century in a number of scientific disciplines. Industrialization, electrification, the exchange of scientific and technical information, transport and communication necessitated negotiation about norms, measures, units, standards, notations, conventions—issues in which precision was both condition and effect. *The Values of Precision*, edited by M. N. Wise (Princeton, NJ, 1995). Th. M. Porter describes how the rise of numeric precision in the nineteenth century was related to the growing government bureaucracy. The faith based on personal authority that was typical of the old administrative élite was replaced by quantification and standardization and an increased trust in numbers. Th. M Porter, *Trust in Numbers. The Pursuit of Objectivity in Science and Public Life* (Princeton, NJ, 1995). A related set of articles discusses the layered history of objecivity, with its diverse ways of excluding the various subjective characteristics of researchers; see L. Daston, 'Baconian Facts, Academic Civility, and the Prehistory of Objectivity', *Annals of Scholarship: Metastudies of the Humanities*, 8 (1991), 337–63; L. Daston, 'Objectivity and the Escape from Perspective', *Social Studies of Science*, 22 (1992), 597–618; L. Daston and P. Galison, 'The Image of Objectivity', *Representations*, 40 (1992), 81–128.

[5] Much historical research is concerned specifically with quantification. See, for example, *The Probabilistic Revolution*, 2 vols (Cambridge, MA, 1987), II, 'Ideas in the Sciences', edited by L. Krüger, G. Gigerenzer and M. S. Morgan; I. Hacking, *The Taming of Chance* (Cambridge, 1990). In this case, we focus on the organization of the psychological experiment. Numerals are but one of the exact effects of this organization.

A case like this can be contextualized in a variety of ways. It is part of the history of the emergence of psychology as a discipline in Germany, but it can also be interpreted as an investigation into the influence of the natural sciences on psychology, or as an account of the increasing importance of error reduction in nineteenth-century science. We shall certainly touch on these matters. But one aspect we think sets our case apart from analyses of precision in sciences outside experimental psychology is Wundt's particular object of study. Wundt and his collaborators aimed at measuring processes in what has been called 'the generalized mind', those parts of mental life shared by all human adults alike.[6] This feature of his research, we intend to argue, is consequential for the conceptual analysis of precision measurement in experimental psychology.

After a short introduction on the origin and early development of mental chronometry, we will present a sketch of Wundt's efforts to reach the degree of precision he considered necessary for the measurement of mental processes: one-thousandth of a second. Guided by Shapin and Schaffer's 'three technologies', we will first consider the material and literary organization of reaction-time experiments.[7] These aspects are then briefly set against the background of the rise of metrology in German science and technology. Next we will argue that measurement of the generalized mind called for a calibration of the social aspects of experimentation as well. Our attention to the social and personal discipline effectuated in Wundt's laboratory brings out the close and consequential connection between the material apparatus and the laboratory's social order. As a case-within-a-case, the experiments of Wundt's young American assistant James McKeen Cattell will serve as an illustration of the elaborate 'social technology' required in mental chronometry. Finally, we will deal with the way ideals of precision came to be distributed in late nineteenth-century psychology. Although material, literary and social technologies spread to new laboratories separately, their proper and precise functioning depended on reassembling them on the spot. We intend to show that the forceful attempts to bring precision and uniformity to the experimental situation resulted in some arcane and paradoxical consequences.

2. The speed of thought

A late nineteenth-century psychological laboratory calls to mind a watchmaker's shop. Even the most scantily equipped laboratory would possess a chronoscope, a clock-like instrument registering reactions in thousandths of seconds.[8] For classroom trials a demonstration chronoscope was often available, a huge contraption with two

[6] K. Danziger, *Constructing the Subject: Historical Origins of Psychological Research* (Cambridge, 1990), 52.

[7] In their classic study of the controversy between Boyle and Hobbes on the interpretation of the void, Shapin and Schaffer introduced a distinction between a material, a literary, and a social technology. Material technology is concerned with the instruments and apparatus with which to produce 'matters of fact'. In his experiments Boyle used an air pump, an elaborate machine demanding endless preparations and adjustments. Literary technology refers to a set of procedures for the 'multiplication of witnessing experience'; because the experiments with the air pump were conducted under semi-public conditions, Boyle attempted to turn his readers into 'virtual witnesses'. To achieve this he published graphic descriptions of the experiments and included illustrations that were drawn in such a way as to give the reader the distinct impression that he/she was one of the spectators. Social technology, finally, specifies the conventions that scientists should follow in dealing with each other and the rules to be observed in considering knowledge claims. S. Shapin and S. Schaffer, *Leviathan and the Air-Pump; Hobbes, Boyle, and the Experimental Life* (Princeton, NJ, 1985).

[8] W. O. Krohn, 'Facilities in Experimental Psychology at the various German Universities', *American Journal of Psychology*, 4 (1892), 585–94.

dials, of which the largest diameter measured 46 cm.[9] On a smaller scale, chronometers and stopwatches were also present. A chronograph would be used to make a time trace—a curve in sooted paper. All these chronometrical instruments—and their peripherals: batteries for the chronoscopes, resistors, electromagnets, telegraph keys, wires, switches—were used to measure reaction times.

Reaction-time research was part of the experimental programme that originated in the problem of the 'personal equation', the discrepancies between observers in timing star transits.[10] These differences suggested that perception might not be an instantaneous process. Helmholtz was the first to suspect that the velocity of the nerve impulse had a measurable speed and proceeded to devise an experimental set-up for physiological measurements on the extremely minute time-scale of nervous processes.[11] Helmholtz's Dutch colleague in physiology F. C. Donders was to give this research a distinctly *psychological* twist. From 1865 Donders struggled with the question of whether the duration of elementary processes, such as distinguishing, willing, and choosing, could be measured. In an experiment that was to mark the birth of 'mental chronometry', an electrode was attached to both feet of an experimental subject. In one of the experimental conditions, the subject was told beforehand whether the stimulus—a mild shock—would be administered to the left or to the right foot. He was instructed to move his hand as quickly as possible on the side he felt the stimulus, thus breaking an electric switch. In the other condition, the subject did *not* know on which side the stimulus would be presented. Donders's apparatus, which he had taken over from the Utrecht observatory with slight adaptations, registered the difference in time between the two conditions: one-fifteenth of a second.

This time-span, in itself negligible in length, held immense meaning for early experimental psychology. Until then, psychological processes were thought to be too fast to determine. Donders's registration of the reaction time marked the moment the human mind changed into an area accessible for measurement.[12] Sensing the significance of the occasion, Donders added to the description of the experiment a solemn note: 'This was the first determination of the duration of a well-defined mental process. It concerned the decision in a choice and an action of the will in response to that decision.'[13]

[9] Demonstration, and more generally education, was the main task of late nineteenth-century German science. Many pieces of apparatus existed in at least two versions: as a research instrument, and as a bigger and bolder version for educational purposes. On the relationship between research and teaching in physics see K. M. Olesko, 'Michelson and the Reform of Physics Instruction at the Naval Academy in the 1870s', in *The Michelson Era in American Science 1870–1930. AIP Conference Proceedings 179*, edited by S. Goldberg and R. H. Stuewer (New York, 1988), 111–32, and K. M. Olesko, *Physics as a Calling: Discipline and Practice in the Königsberg Seminar for Physics* (Ithaca, 1991).

[10] D. Draaisma, 'De Chronometrie van de Geest', in *Vensters op de Geest. Cognitie op het Snijvlak van Filosofie en Psychologie*, edited by C. Brown, P. Hagoort and Th. Meijering (Utrecht, 1989), 22–48; S. Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context*, 2 (1988), 115–45.

[11] F. L. Holmes and K. M. Olesko, 'The Images of Precision: Helmholtz and the Graphical Method in Physiology', in M. N. Wise (note 4), 198–221.

[12] This change in the intuitions about the relation between the human mind and time is explored in Draaisma, 1989 (note 10).

[13] F. C. Donders, 'Over de Snelheid van Psychische Processen', *Nederlandsch Archief voor Genees- en Natuurkunde*, (1869), 117–45. In 1868 Donders's article also appeared in German and French. In the English translation, the original term 'psychisch proces' is translated by 'neural'; however, the context makes it clear that by 'psychisch' Donders meant 'psychological' or 'mental'. 'On the Speed of Mental Processes', translation of Donders (1869), in *Acta Psychologica* 30, *Attention and Performance II*, edited by W. G. Koster (1969), 412–31.

Donders did not continue this line of research. Reaction-time research was taken up as a psychological measure by Wundt and his collaborators in a thorough and elaborate programme of mental chronometry. The principle of Donders's experiment was preserved: the duration of a psychological process was defined as the prolongation of the reaction time caused by adding that process. The Leipzig psychologists varied the nature and the intensity of the stimuli, systematically working through all of the senses, researching simple and complex reactions, as well as the influence of learning and attention, and the effect of intoxicants such as alcohol, chloroform, and morphine, but also tea and coffee, etc. In a relatively short time, Wundt's laboratory was producing vast amounts of tables and charts which showed the duration of simple psychological processes, given the type of stimulus and the kind of reaction. Some of the most extensive maps of the temporal atlas of the human mind were drawn in Leipzig.[14]

Reaction-time measurement achieved a prominent place in the experimental repertoire that turned psychology into a counting, a calculating, a measuring science. But the mere fact that a science measures, counts, and calculates does not make it an *exact* science. An instrument can only be said to measure precisely once standards of precision are available.[15] Such standards were developed in psychology's early experimental practice. It took the Leipzig laboratory well over twenty years to reach the level of precision that, in Wundt's eyes, one should be able to expect from a psychological experiment. At the end of those twenty years, Wundt had a virtual procession of chronometric instruments at his disposal. Heading this procession was the Hipp chronoscope.

3. The chronometric arsenal

The instrument which was to contribute so much to the quiet punctuality of psychological experimentation had its parentage in the noisy business of English artillery. In 1840, Charles Wheatstone constructed a clock-like device for measuring the velocity of projectiles. Using the principle of his earlier invented electromagnetic telegraph, Wheatstone stretched a thin line across the mouth of the gun, the firing of which broke an electric circuit. This activated a switch that closed the circuit of an electric clock. The impact of the shot broke the circuit again. While the circuit was closed the hands of the clock were running. After the trial the arrested pointer gave a reading of the interval between shot and impact. In 1842, the Swiss watchmaker and mechanic Mathias Hipp built an improved model of Wheatstone's instrument.[16] In his first model Hipp used a vibrating spring (500 vibrations per second) as a regulator. In later models he incorporated springs vibrating twice as fast. At each vibration one tooth was allowed to pass, as in a clock escapement. The clock was weight driven.

[14] Early examples are: M. Friedrich, 'Über die Apperceptionsdauer bei einfachen und zusammengesetzten Vorstellungen', *Philosophische Studien*, 1 (1883), 39–77; M. Trautscholdt, 'Experimentelle Untersuchungen über die Association der Vorstellung', *Philosophische Studien*, 1 (1883), 213–50; E. Kraepelin, 'Über die Einwirkung einiger medicamentöser Stoffe auf die Dauer einfacher psychischer Vorgänge', *Philosophische Studien*, 1 (1883), 417–62; 572–605.

[15] 'Alone, precision measurement does not a standard make'; K. M. Olesko, 'Precision, Tolerance, and Consensus: Local Cultures in German and British Resistance Standards', in *Archimedes. Scientific Credibility and Technical Standards*, edited by J. Z. Buchwald (Dordrecht, 1996), 117–56 (at p. 118).

[16] On Wheatstone and Hipp, see B. Edgell and W. L. Symes, 'The Wheatstone–Hipp Chronoscope; its Adjustments, Accuracy, and Control', *British Journal of Psychology*, 2 (1906), 58–88; H. Gundlach, 'The Hipp Chronoscope as Totem Pole and the Formation of a new Tribe—Applied Psychology, Psychotechnics and Rationality', *Teorie & Modelli*, 1 (1996), 65–85.

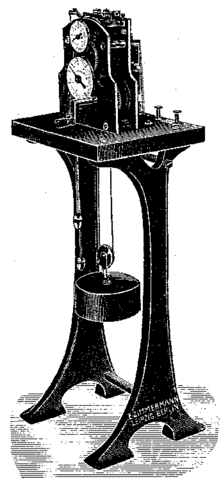
E.ZIMMERMANN
LEIPZIG·BERLIN

Nr. 1260–1261. **Chronoskop nach Hipp.**

Chronoscope according to Hipp.

Chronoscope de Hipp.

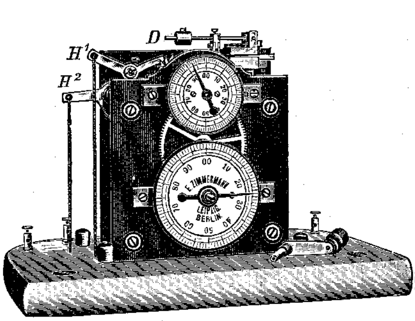
Cronoscopio de Hipp.



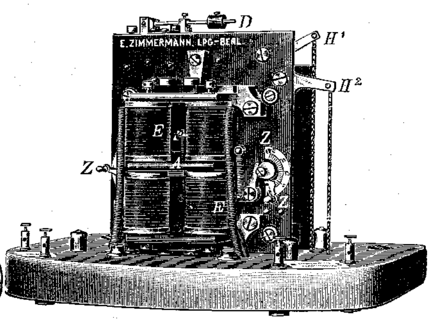
ca. 1/10 nat. Größe

Nr. 1260. Genauestes Uhrwerk zur Zeitmessung mit direkter Ablesung von $^1/_{1000}$ Sekunden = 1 Teilstrich des oberen und von $^1/_{10}$ Sek. = 1 Teilstrich des unteren Zifferblattes. Durch die doppelte Magnetenanordnung wird das Zeigerwerk entweder bei Strom-öffnung oder -schließung in Bewegung gesetzt. Der Übergang von der einen zur anderen Benutzung erfordert entsprechende Spannung der Abreißfedern des Ankers, welche an Skalen Z einstellbar und der Stromstärke und Widerstand genau angepaßt werden müssen.

Die Schutzglocke besitzt eine Bohrung für den Aufzugsschlüssel, so daß dieselbe beim Aufzug nicht abgenommen zu werden braucht. Das Uhrwerk zeichnet sich durch einen sehr gleichbleibenden Ton der Regulierfeder aus.



ca. 1/4 nat. Größe



ca. 1/4 nat. Größe

Laufzeit: ca. $1^1/_2$ *min.*

Meßgenauigkeit: m V = 2,5 σ

Voltzahl: 6 Volt Akk.

Gewicht: netto 13,500 kg

Literatur: Wdt. III. 365

Grundzahl: 650

Dazu vergl. Nr. 1264b–1268.

* *110* *

Figure 1. The Hipp chronoscope as depicted in the Zimmermann catalogue (1928). The Hipp chronoscope has two dials. The hand of the upper dial revolves once in one-tenth of a second, the hand on the lower one makes one complete turn in ten seconds. The upper dial indicates milliseconds. The hand for the lower dial revolves one hundred times slower. The electromagnet *E* at the back of the instrument pulls the armature to the clockwork. The small levers H^1 and H^2 are for operation by hand. *Source*: E. Zimmermann, *Wissenschaftliche Apparate*, *Liste 50* (Leipzig, Berlin, 1928), 110.

An essential feature of the Hipp chronoscope was that the hands of the clock were not directly connected to the clockwork. Consequently the clock could be set in motion while the hands remained stationary. The connection between clockwork and armature was operated by an electromagnet. As soon as an electric current was sent through the coil of the magnet, the armature was attracted to the clockwork and the hands started to move. When the current was broken the armature was pulled back by a spring, arresting the hands.[17] The Hipp chronoscope worked more or less like a huge electric stopwatch.

Although technically advanced, the Hipp chronoscope was extremely sensitive to disturbances. For one thing, the regulator spring sometimes changed pitch to the lower octave, vibrating with about half the speed it should. Unfortunately this deviation was not sufficiently uniform to be corrected by a simple doubling of the readings. Equally troubling was the electromagnetic operation of the armature. If a weak current was sent through the coil it would take an indeterminate interval before the iron was sufficiently magnetized to attract the armature. A strong current, on the other hand, introduced the error of remanent magnetism, holding the armature too long. Still another problem was the force of the spring on the armature: a strong spring would pull back the armature for indefinite fractions of seconds earlier than a weak spring would have.

Terms such as 'deviation' and 'error' of course presuppose the availability of a standard. Wundt was well aware of this problem and tried to cope with it by constructing an instrument which could serve as a standard for correction: the *Controllhammer*.[18]

The control hammer worked according to the principle of the timed fall. The head of the hammer was held up by an electromagnet (*E*). If the current was interrupted, the hammer fell, passing a contact (C_1 or C_2) which opened an electric circuit. At the bottom the head hit a second contact (C_3 or C_4) which closed the circuit again. Both the height of the electromagnet and the counterweight (*P*) on the steel of the hammer could be adjusted to manipulate the length and speed of the fall. This, of course, meant that the control hammer itself demanded an instrument to determine the actual interval of the fall.

At this point it will have become apparent that the process of experimentation was not a straightforward matter of registering responses and checking the readings against a standard. Each reading could only be accepted as an accurate measurement by an implicit reference to an instrument next in line, calibrating its predecessor. This immediately raises a *logical* question. If each calibration instrument begs the question of its own calibration, if each calibration is merely a link in an infinite regress, then how can one ever accept a specific reading as the 'true' or 'actual' time taken up by the psychological process under study?

In the philosophy of science this is a familiar problem, inherent to each form of measurement. It has a long and fascinating history in the technology of timekeeping, where it took the form of the question of how one was to measure the precision of clocks claimed to be the most accurate then available. This history informs us that the infinite regress is generally broken by procedures that necessarily have a certain degree of arbitrariness. John 'Longitude' Harrison's eighteenth-century precision

[17] In an earlier version of the chronoscope, the hands moved when the current was broken. In the new chronoscope, thought much more convenient by Cattell, the hands moved when the circuit was closed. J. McK. Cattell, 'Reaction', *American Journal of Psychology*, IV (1892), 596–7.

[18] W. Wundt, *Grundzüge der physiologischen Psychologie* (Leipzig, 1887), 3rd edn, Bd. II, 276.

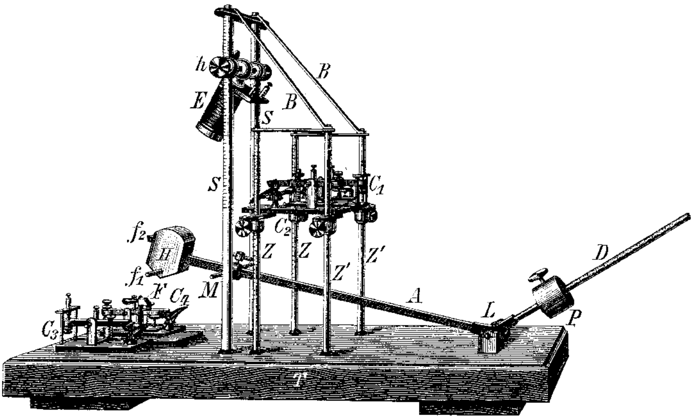


Figure 2. Control hammer after a design by Wundt. The large model depicted here can be adjusted to intervals between 100 and 600 milliseconds. *Source*: W. Wundt, *Grundzüge der physiologischen Psychologie*, 4th edn (Leipzig, 1893), part II, 331.

chronometers, for instance, were checked against an astronomical 'clock': the rotation of the earth as measured by star transits, a periodicity accepted—provisionally and by convention—as the final standard.[19]

Such movements in the nightly firmament were not much use to Wundt and his collaborators. They needed a device that could be placed on a laboratory table, an instrument that could calibrate the control hammer. Wundt's practical solution to the problem of a potentially infinite procession of instruments was provided by the *Chronograph*.

The chronograph consisted of a drum with a circumference of 62 cm, covered with glazed paper of the finest quality, sooted above a flame of turpentine oil. While the drum revolved at high speed, a writing device moved slowly and steadily to the right along an axis parallel to the drum. This writing device contained a tuning fork (500 vibrations per second) and three pins. The vibrations of the tuning fork marked a time trace (via a beard hair). The duration of the other traces—for instance, the interval between stimulus and response—could be determined by comparing them with the time trace.[20] The chronograph was accurate to one-ten-thousandth of a second.

Of course, the chronograph was not really the ultimate in Wundt's line-up of time-measuring devices. The tuning fork demanded calibration in order to be sure that it vibrated exactly 500 times per second. The same went for the ten rotations per second of the drum, or the supposedly uniform motion of the writing head. In point of fact, Wundt himself advised checking the chronograph with the help of a control apparatus constructed by Ludwig Lange.[21] Neither technically nor logically could the chronograph possibly provide the absolute standard to calibrate all other instruments. The privileged position of the chronograph in Wundt's configuration of chronometric

[19] Howse writes about the construction of clocks that could measure long periods of time—the time spent at sea on a ship, at the shortest a couple of months—to the second. But a month, a day or even a minute is an eternity in comparison with the fraction of a second passing between the presentation of a stimulus and the reaction by the subject. D. Howse, *Greenwich Time and the Discovery of Longitude* (London, 1980).

[20] Wundt (note 18), 280.

[21] L. Lange, 'Ein Chronograph nebst Controlapparat für sehr genaue Zeitmessungen', *Philosophische Studien*, IV (1888), 457–70.

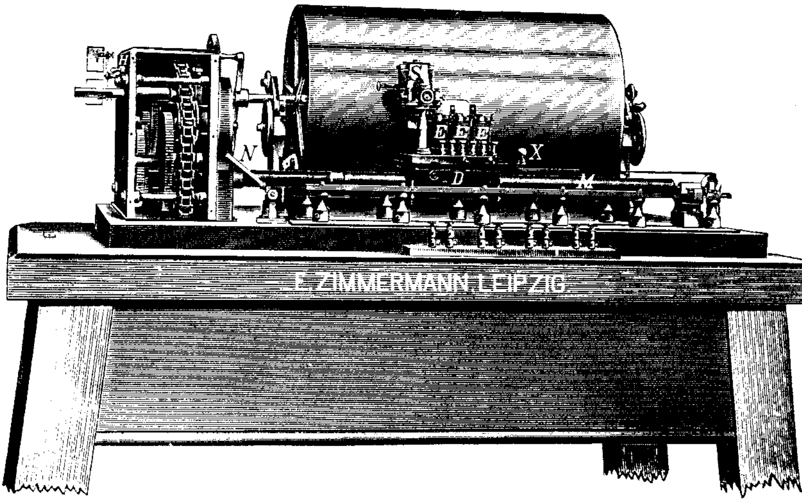


Figure 3. Chronograph. The chronograph had its origin in astronomy, where it was used for registering star transits. Wundt adjusted the instrument for the measurement of extremely short intervals. The drum makes up to ten rotations per second, driven by clockwork (left). The tuning fork writing the time trace (*S*) is set into vibration by a secondary tuning fork, which is itself kept in vibration by an electromagnet. *Source*: E. Zimmermann, *Preisliste über psychologischen und physiologischen Apparate*, XVIII (Leipzig, 1903), 66.

machinery had to do with the practical necessity to break the regress *somewhere*.[22] After all, Wundt and his collaborators had committed themselves to a time-consuming experimental programme.

To convince his readers of the superiority of this new standard, Wundt referred to a series of experiments by Lange, which showed that the chronograph reduced the mean error in reaction-time experiments to *c*. 0.03 milliseconds.[23] The mean error of the Hipp chronoscope was about ten times as large.[24] Justifiably proud of the 'Feinheit und Genauigkeit' of his chronograph, Wundt advised others to employ the chronograph to check all other devices, including the Hipp chronoscope and the control hammer.[25,26] The hierarchically higher position of the chronograph even manifested itself in a subtle shift of terms: whereas the control hammer served to *check* other instruments ('Control', 'Correctur'), the chronograph provided a means

[22] Discussing the Königsberg seminar in physics, Olesko concludes that the 'ethos of exactitude demanded the attainment of accuracy and precision through error analysis, but it was a goal that could never be completely realized. Absolute certainty lay somewhere in the infinite, not only because it was unattainable in practice but also because if it were achieved, the investigative enterprise in physics would itself collapse. In terms of the practice of physics, the ethos emphasized performance over product, means endlessly pursued over ends decisively achieved' (note 9, 450).

[23] Lange (note 21).

[24] The insight into the specific characteristics of apparatus was the result of experiments explicitly aimed at researching or testing the instrumentation. Knowledge in psychology was thus not confined to the human mind, but included the procedures and techniques used by the experimenter. See, for instance, for research on the functioning of the chronoscope: Edgell and Symes (note 16).

[25] W. Wundt, *Grundzüge der physiologischen Psychologie* (Leipzig, 1893), 4th edn, Bd. II, 343.

[26] This advice was not undisputed as is apparent from the debate that briefly sparked up between Wundt and his former assistant, Cattell, about the order in which different instruments should calibrate one another. See J. McK. Cattell (note 17); J. McK. Cattell, 'Chronoskop und Chronograph',

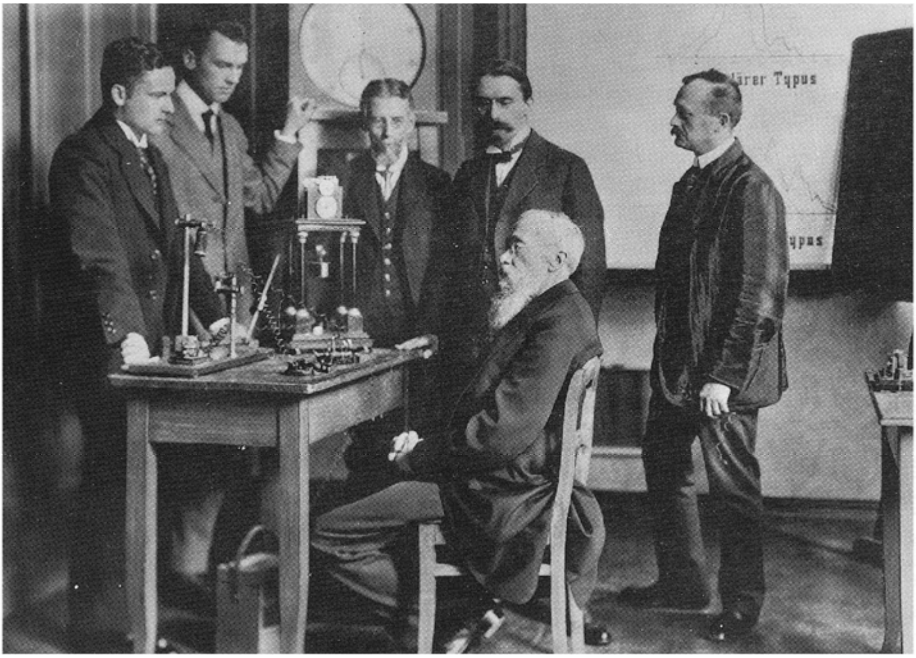


Figure 4. Surrounded by his collaborators Wundt sits at a table with chronometric instruments. By his right hand stands a Hipp chronoscope, by his left the large version of the control hammer. In front of Wundt lie a telegraph key and a rheostat. In the background stands the large demonstration chronoscope. The man at the far right is Hartmann, one of Wundt's technicians, in accordance with his social position one step behind the others. *Source*: W. Meischner and E. Eschler, *Wilhelm Wundt* (Keulen, 1979), 88.

for their *calibration* ('Aichung').[27] Once the Leipzig 'Präcisionsmechaniker' E. Zimmermann placed it in serial production, the chronograph confirmed its special status by being the most expensive instrument in the catalogue: to purchase a chronograph cost 1010 marks, more than twice the price of the hardly less impressive demonstration chronoscope (440 marks). The chronograph was a precious instrument indeed.[28]

4. A paper cycle: journals, catalogues, and textbooks

The procession of instruments together rapidly approaching Wundt's ideal of precision provided a standard for what counted as proper experimentation. This standard was not only expressed in the apparatus as it stood, surrounded by paraphernalia, on the laboratory tables, but also in the literature that described and

Philosophische Studien, IX (1894), 307–10; W. Wundt, 'Chronograph und Chronoskop', *Philosophische Studien*, VIII (1893), 653–4; W. Wundt, 'Bemerkungen zu vorstehendem Aufsatze', *Philosophische Studien*, IX (1894), 311–15. Cattell defended his 'Fallschirm', the instrument he had originally constructed to briefly reveal visual stimuli. See R. Benschop, 'What is a Tachistoscope? Historical Explorations of an Instrument', *Science in Context*, 11 (1) (1998), 23–50.

[27] We use terms such as 'Control', 'Aichung', 'Feinheit', and 'Genauigkeit' to designate a concern with the ideal of what we have called precision. For a more thorough determination of these terms, see, for example, K. M. Olesko, 'The Meaning of Precision: The Exact Sensibility in Early Nineteenth-Century Germany', in M. N. Wise (1995) (note 4), 103–34 (at pp. 110 ff).

[28] E. Zimmermann, *Preisliste über psychologische und physiologische Apparate*, XVIII (Leipzig, 1903).

promoted these instruments. Three different texts were particularly important in the Leipzig context: the *Philosophische Studien*, the journal of which Wundt was both founder (in 1881) and editor; the Zimmermann catalogues of scientific apparatus; and the famous and copious *Grundzüge der physiologischen Psychologie*, Wundt's definition of the new psychology, which appeared from 1873–74 until 1908–11 in six ever-expanding and adapted editions.[29]

The very first article to appear in the *Philosophische Studien*, authored by Wundt, was 'On Psychological Methods'. Scientific psychology distinguishes itself, Wundt wrote, from the usual psychology (using 'Selbstbeobachtung', self-observation) 'in that her description wants to be precise'.[30] This precise description can be witnessed in the journal for pages on end. The authors provided elaborate tables, charts, mathematical formula, and graphs in the articles presenting experimental results. The descriptions of experimental research habitually included a paragraph on the organization of the experiment: what kinds of apparatus were used, how they were connected to and driven by other equipment, how the currents moved along the intricate circuits, and finally what chronological steps the set-up went through during different experimental trials.

In the *Philosophische Studien* (as well as in other journals), the description of the apparatus was often supplemented by a footnote, for instance stating: 'The instrument described was made under my supervision in Carl Krille's mechanics workshop in Leipzig; he can provide duplicates'.[31] Reference was also often made to the catalogue published by Zimmermann. Much of the apparatus belonging to Wundt's experimental programme was developed by Zimmermann, whose company proved extremely successful.[32] The catalogues and price lists were filled with woodcuts and brief descriptions of instruments of all kinds. These instruments, Zimmermann assured the reader, were treated with the utmost care. Before inclusion in the catalogue, they had been checked thoroughly: 'The delivery is made with a full guarantee after careful testing; where possible, experimental trials are done.'[33] Not only were they thoroughly checked but Zimmermann promised to stay at the cutting edge of the discipline by reserving 'the right to deviate from the woodcuts and descriptions, as well as make changes in the price, as instigated by improvement of the apparatus'.[34] When these meticulously tested, up-to-date instruments were sent to whichever psychologist had ordered them, they were packaged carefully to ensure unscathed transportation. The care taken in dealing with the instrumentation is also reflected in Zimmermann's stern warning protecting the status of his catalogue: 'Reprint and translation, as well as use of my illustrations without my consent, are

[29] D. Draaisma and S. de Rijcke, 'The Graphic Strategy. Illustrations of Experimental Apparatus in Wundt's *Grundzüg*' (submitted).

[30] W. Wundt, 'Ueber psychologische Methoden', *Philosophische Studien*, 1 (1883), 1–38 (at p. 3).

[31] J. McK. Cattell, 'Psychometrische Untersuchungen', *Philosophische Studien*, 3 (1886), 305–35; 452–92 (at p. 308).

[32] Apparatus was of course described in other journals and handbooks as well—often expressing other conceptions of what the discipline entailed: for example, the *Zeitschrift für die Psychologie und Physiologie der Sinnesorgane* (founded in 1890) and a little later the *Archiv für die gesamte Psychologie* (founded in 1903). Sommer's list of the apparatus exhibited at the 1904 conference of experimental psychology in Gießen resembles Zimmermann's catalogue with its numbering of the instruments, reference to original sources and brief descriptions, Dr Sommer, *Die Ausstellung von experimental-psychologischen Apparaten und Methoden bei dem Kongreß für experimentelle Psychologie* (Leipzig, 1904). See also the *Psychological Laboratory of Harvard University* (Cambridge, MA, 1893) with beautiful photographs of instruments and the interior of the laboratory room.

[33] 'Bezugs-Bedingungen' (note 28).

[34] Ibid.

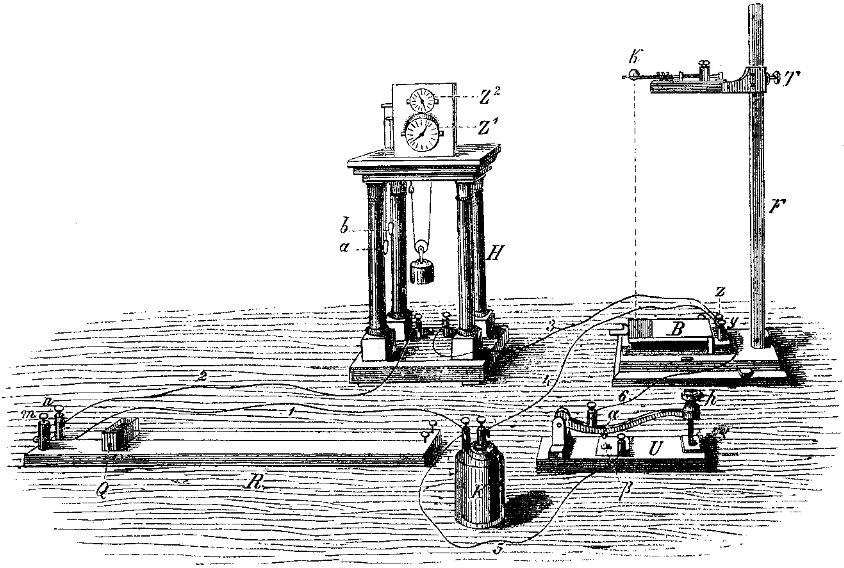


Figure 5. An illustration from the third edition (1887) of Wundt's *Grundzüge* showing a configuration of apparatus for a reaction-time experiment. *Source*: W. Wundt, *Grundzüge der phsyiologische Psychologie*, 3rd edn (Leipzig, 1887), part II, 275.

prohibited.'[35] Another way in which the quality of his merchandise became visible was the reference to scientific publications in which the instruments listed in the catalogue were depicted and described in more detail. These descriptions appeared in publications associated with Leipzig, such as the *Philosophische Studien.* Besides being closely affiliated with Wundt's laboratory, Zimmermann claimed to have direct contact with a host of similar laboratories.[36] The instruments listed in his catalogue came not only from Wundt; he included apparatus 'after', for example, Wirth, Müller, and Sommer.[37] Thus, Zimmermann referred to scientific publications of psychologists, and they—the Leipzig psychologists—returned the favour on a regular basis. Both referred to a source held in high esteem by many: Wundt's *Grundzüge.*

In this book, Wundt gave his vision of the new discipline of psychology. He described the topics to be dealt with, as well as the manner in which these were to be approached. From the second edition of the *Grundzüge* (1880) on, Wundt included a separate paragraph on chronometric instruments and methods. This paragraph expanded from seven pages (and two illustrations) at its first appearance, to 22 pages (and 11 illustrations) in the fourth edition (1893).[38] A graphical demonstration of Wundt's pursuit of precision is provided by a comparison of two illustrations from consecutive editions of the *Grundzüge.*

The illustration in Figure 5 is from the third edition (1887) and shows a configuration of apparatus for a reaction-time experiment. The subject is presented

[35] Ibid.

[36] Ibid.

[37] As a commercial enterprise Zimmermann could be considerably more generous in its reference policy than most journals were. In the *Zeitschrift für die Psychologie und Physiologie der Sinnesorgane* Zimmermann was not a regular entry. The *Archiv für die gesamte Psychologie* did include references to the *Philosophische Studien* and the *Grundzüge der physiologischen Psychologie.* Both journals did refer to other instrument makers or lab technicians from whom apparatus could be obtained.

[38] W. Wundt, *Grundzüge der physiologischen Psychologie* (Leipzig, 1880), 2nd edn, Bd. II, 230–7; W. Wundt (note 25), 322–44.

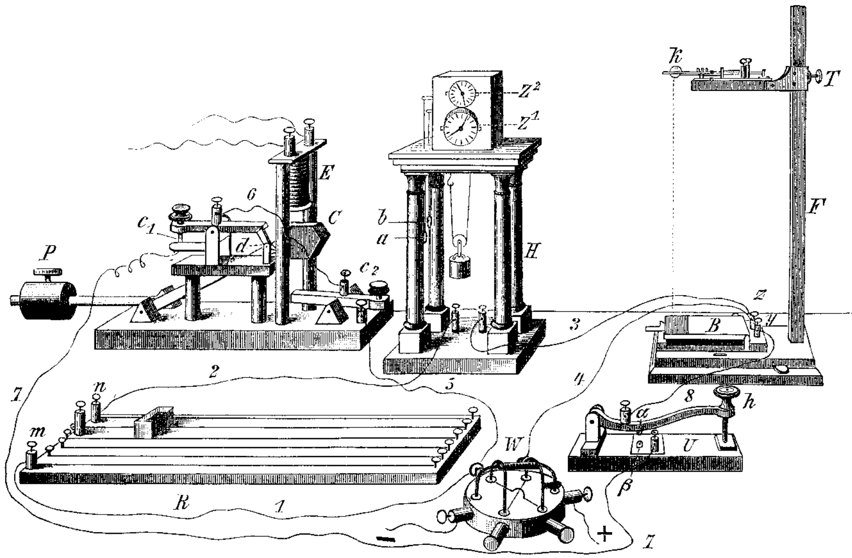


Figure 6. An illustration from the fourth edition (1893) of Wundt's *Grundzüge* showing a configuration of apparatus for the same experiment as in Figure 5. *Source*: W. Wundt, *Grundzüge der phsyiologische Psychologie* 4th edn (Leipzig, 1893), part II, 322.

with an acoustic stimulus: the sound of a bullet hitting a floorboard after having been released in the *Fallapparat* (*F*). The impact of the bullet closes an electric circuit, supplied by a battery (*K*) and regulated by a rheostat (*R*). The current starts the chronoscope. Immediately after the subject hears the sound of the bullet he lifts his finger from a telegraph key (*U*). Consequently, the current is broken and the hands of the chronoscope stop, allowing the experimenter a reading of the reaction time.

Figure 6, an illustration from the fourth edition (1893), is a set-up for the same experiment, but with a drastically refined and expanded configuration of instruments. The rheostat is shown in a technically more advanced model. The now old-fashioned battery has disappeared; the source of electricity is invisible, only the 'Pohl'sche Wippe' (*W*) is shown, an instrument for directing the current. Next to the chronoscope stands a control hammer, required for checking its neighbour. Not shown, but essential in the background of this set-up, is the chronograph, on which the control hammer was to be calibrated.

In his *Grundzüge*, Wundt only included experiments that were conducted with 'a strict methodology' and produced 'exactly determined' reactions. The text is sprinkled with terms like 'exactness', 'precision', 'constancy', 'uniformity', 'regularity', 'reliability', 'standardization', and so forth. It is clear, then, that the instruments featuring in experiments were an important site where precision is constructed. The Leipzig research programme was to be conducted on the terms of an extremely strict chronometric regime. The instruments that were used in Leipzig experiments to establish and execute this regime could also be obtained from Leipzig, as is made visible in the three literary sources described here. The articles in the scientific journals, together with Wundt's seminal work, secured the scientific status of the apparatus. It seems likely that the status of Zimmermann's wares was further supported by his unproblematic combining of psychological and physiological instrumentation—the head of the price list refers to 'psychological and physiological apparatus'—or by his reference to journals such as *Zeitschrift für Psychologie und*

Physiologie der Sinnesorgane.[39] By including references to many different kinds of experimenters, he avoided siding with any one view of what his potential market should be.

The Leipzig concern with accuracy was proclaimed in texts that were to reach far beyond the walls of the laboratory. 'It is interesting to note', Cattell reflected, 'that the example set by Wundt at Leipsic [*sic*] is being followed in other universities. Psychological laboratories have been established or are being planned at Berlin, Bonn and Göttingen; in America, at Johns Hopkins, Harvard, Pennsylvania, and Princeton; in England, at Cambridge; also at Copenhagen and elsewhere.'[40] Later editions of the Zimmermann catalogue, originally printed in German, began to appear with instruments named in other languages as well. The 1928 catalogue features instruments translated into English, French, and Spanish. The publications originating in Leipzig described the terms in which experimental psychology was to be conducted. These terms surrounded the instrumentation with a vocabulary that informed their users where to find them, what to do with them, and how to assess their value.

5. Metrology

Wundt and his collaborators were not alone in their preoccupation with precision. Throughout the nineteenth century, in science, in industry and in government bureaucracy, different genres of precision emerged. One of the most striking domains in which a concern with precision developed was *metrology*. The mid-nineteenth century saw the growth of this new branch of physics, a science dedicated to the creation and improvement of measuring methods, instruments, and physical units and standards. Metrology became a fast-moving front in physics. For Wundt's contemporaries in physics laboratories and technical institutes, matters of calibration and standardization increasingly became a central concern. Whether they were constructing or refining thermometers, barometers, calorimeters, galvanometers, voltameters, manometers, photometers, or polarimeters, for the new generation of physicists 'measurement became the shibboleth of scientific progress'.[41] Already in 1872 a group of scientists and industrialists—among them Wundt's former teachers Hermann von Helmholtz and Emil Du Bois-Reymond—issued a memorandum calling for state support in advancing precision-mechanical research. This so-called Schellbach Memorandum was warmly supported by Werner von Siemens and led eventually, in 1887, to the establishment of the *Physikalisch-Technische Reichsanstalt*, the world's first institute devoted largely to the science and technology of precision measurement. Its first director was Helmholtz. Previously, this 'Reichskanzler der deutsche Wissenschaft' worked in Heidelberg where Wundt served as his assistant from 1858 to 1863.[42] In those years, Wundt received intensive training in the preparation of experimental set-ups, for both research purposes and education. During Wundt's years as a professor in Leipzig, Gustav Wiedemann, a prominent experimentalist in matters of standardization, was a colleague in the physics

[39] After 1907 this journal split into the *Zeitschrift für Psychologie* and the *Zeitschrift für die Physiologie der Sinnesorgane*.

[40] J. McK. Cattell, 'The Psychological Laboratory at Leipsic', *Mind*, XIII (1888), 37–51, (at p. 39).

[41] D. Cahan, *An Institute for an Empire. The Physikalisch-Technische Reichsanstalt* 1871–1918 (Cambridge, 1989), 12.

[42] Little is known about the relationship between these two men, but for an account, see R. S. Turner, 'Helmholtz, Sensory Physiology, and the Disciplinary Development of German Psychology', in *The Problematic Science: Psychology in Nineteenth-Century Thought*, edited by W. R. Woodward and M. G. Ash (New York, 1982), 154–7.

department. Wiedemann's research at that time was aimed at one of the main metrological problems, the determination of the ohm.[43] Both Helmholtz and Wiedemann, like the experimental practices of physiology and physics at large, set Wundt an example and certainly there are some striking resemblances between Wundt's series of instruments checking instruments and calibration research in industrial settings. The German glass industry, for instance, produced high-quality thermometers. These thermometers were checked with special calibration thermometers. The thermometers used to check the calibration thermometers were checked at the *Reichsanstalt*—with thermometers. Physical measurement and mental chronometry shared a scientific climate in which values such as precision, uniformity, and standardization became crucial. While experimental psychology took over its instruments virtually intact from physiology, as Danziger has remarked, it should be added that Wundt and his collaborators at once took over the emerging concern with physical metrology.[44]

Present-day historians of psychology expect to find precision mainly in the *technology* of measurement. However, in this singular focus on instrumentation and its description, a crucial complication remains unexplored. Experimental psychology may have shared with other scientific disciplines the conventions and material methods of guaranteeing precision; it did not share its object of study. After all, psychology manipulated its instruments in order to grasp the human mind. The programme of mental chronometry involved much more than mechanical precision.

6. 'Ditto, ditto, ditto'

Late in the autumn of 1883, James McKeen Cattell, a 23-year-old American, travelled to Leipzig to pursue his study in experimental psychology. Wundt appointed him as his research assistant and Cattell was granted permission to continue a research project he had started in America.[45] Cattell's work in Leipzig concentrated mainly on the duration of psychological processes involved in recognizing and naming letters and words.[46] Most of these experiments were done with one and the same laboratory partner, Cattell's German friend Gustav Oscar Berger. During his three-year stay in Leipzig Cattell kept a diary. He also wrote a long series of letters to his parents. Both diary and correspondence have been preserved and are, today, a valuable source of information on the daily routine of and around Wundt's laboratory.[47] Cattell's notes from the floor expose mental chronometry's 'backstage', the work that is normally hidden from view in the stylized presentation of findings in articles and dissertations. Wundt may have offered minute descriptions of his attempts to keep the chronometric armamentarium under a strict regime of correction and control; Cattell shows us that the measurement of reaction time called for an equally strict discipline in non-technical domains as well.

The Hipp chronoscope, Cattell was soon to find out, was a cumbersome

[43] G. Wiedemann, *Ueber die Bestimmung des Ohm* (Berlin, 1885); see also note 3.

[44] Danziger (note 6), p. 29.

[45] This was quite unusual. Most students were given assignments by Wundt at the beginning of each academic year. Personal preference or previous work did not count for much in the strictly organized and hierarchically managed context of Wundt's laboratory. For different styles of lab management in psychology, see M. Kusch, 'Recluse, Interlocutor, Interrogator. Natural and Social Order in Turn-of-the-Century Psychological Research Schools', *Isis*, 86 (1995), 419–39, in physiology, D. P. Todes, 'Pavlov's Physiology Factory', *Isis*, 88 (1997), 205–46.

[46] Cattell (note 31).

[47] *An Education in Psychology* (note 2).

instrument to work with. On 12 March 1884 he made an entry that the 'clock was magnetized on one side', yielding times that were too long.[48] On 18 October of that same year he wrote that his instruments were still causing him trouble: 'The apparatus is not yet in working order however—only those who work with electricity and complicated apparatus understand how difficult it is. For example I have a battery of three La Clanché elements—a new element supposed to be especially constant, yet at first it gave a strong current, and a few minutes afterwards would give none at all—it is apparently impossible to find out where the trouble lies.'[49] What Cattell hoped to get from his La Clanché elements, utter constancy, he equally hoped to find in those who operated the instruments: subject and experimenter. On his experiments with Berger, Cattell writes:

> The two subjects [Dr G. O. Berger and the writer] on whom the determinations were made had already had much practice in psychological work. They were in good health and lived regularly, not even using coffee. The experiments were made every morning (except Sunday) from eight to one o'clock. After each series of 26 reactions, a considerable and constant interval elapsed before the same subject again reacted. The subject held his attention as constant as possible, and was not disturbed by noise or the presence of others in the room.[50]

The precision inherent to the procession of calibration instruments reappears in the temporal organization of the experiments: when the trials begin (at 8.00), when they end (13.00), how many trials are done (26), how long the break is between a series of experiments (a considerable and constant interval), etc. Precision, in the shape of punctuality, demanded a strict personal and social discipline. Anything that might cause deviations, any source of disturbance, variation, or distraction, had to be reduced or eliminated.

First of all, constancy could be achieved by having the experiment proceed smoothly. 'It is a matter of no small importance so to arrange the apparatus that it can be conveniently operated on', Cattell writes.[51] Both observer and experimenter had to be able to handle the instrumental set-up without any additional effort. The observer had to be able to see distinctly, sit naturally and speak conveniently.[52] A layout, published by Cattell, locates persons and instruments in a topography aimed at having both subject and experimenter assume their roles without any obstruction or diversion.

Constancy imposed demands of a psychological nature as well. At the beginning of each trial both partners had to be *ready*. The experimenter decided when a trial began by simultaneously starting the clockwork of the chronoscope and calling 'jetzt!'. Whether it was the experimenter or the observer who was then allowed to drop the screen of the gravity chronometer presenting a visual stimulus was less important than fixing the optimal moment when the observer had succeeded in putting himself 'in readiness to make the reaction'.[53]

The observer was to be in a 'normal' state—poised between attention and relaxation. Whatever might endanger this delicate balance, the strain of the

[48] Ibid., 104.
[49] Ibid., 128.
[50] J. McK. Cattell, 'The Time Taken up by Cerebral Operations', *Mind*, XI (1886) 220–42; 377–87; 524–38 (at p. 230).
[51] Ibid., 228.
[52] Ibid.
[53] Ibid., p. 233.

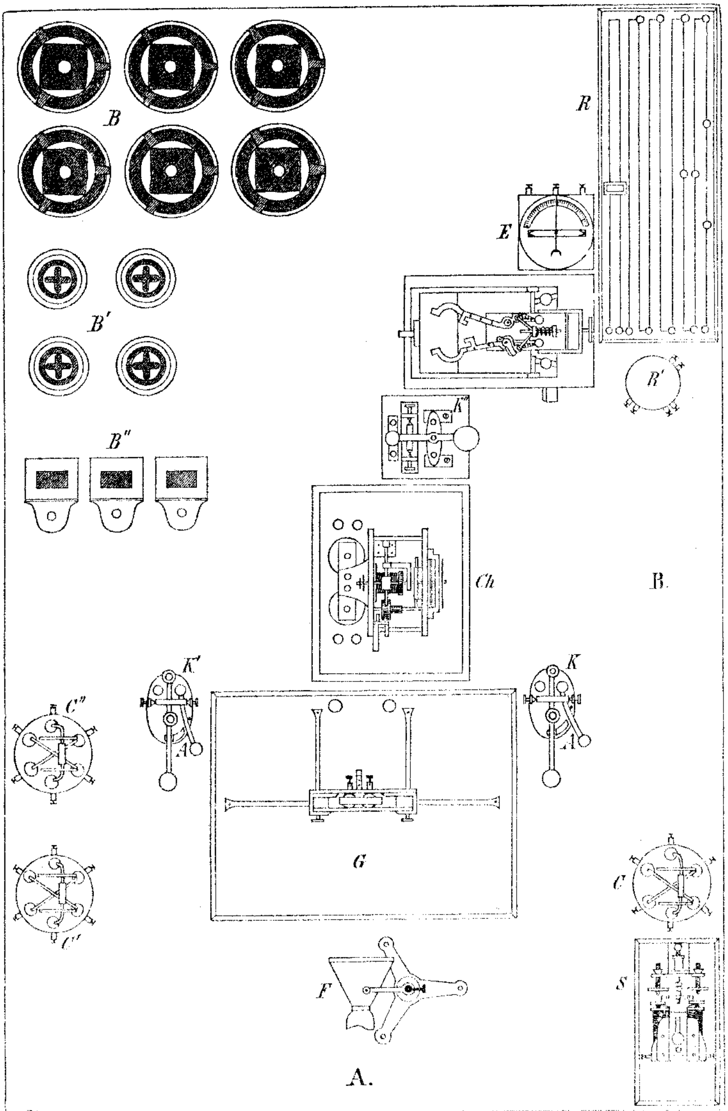


Figure 7. This layout of Cattell's experimental set-up shows the positions of the instruments, the experimenter, and the subject. The subject (*A*) sits at the head of a string of interconnected instruments: batteries (*B*) and rheostats (*R*), an electrometer (*E*), a chronoscope (*Ch*) and a fall chronometer (*G*). Cattell: 'The observer sits at *A*, the light coming over his left shoulder. His head is held naturally, and at the distance of most distinct vision for the word. He can conveniently speak into the mouth-piece of the sound-key *F*, or hold the telegraphic key at *K* closed. The experimenter sits at *B*, within easy reach of all the apparatus he has to control.' *Source*: J. McK. Cattell, 'The Time Taken up by Cerebral Operations', *Mind*, XI (1886), 220–42; 377–87; 524–38, at p. 228.

experimental work itself, for instance, had to be carefully administered. Cattell observed: 'If I spend six hours a day at this work, perhaps two must be given to looking after the apparatus, preparing things &c. This is very easy work indeed. Then in two of the other four hours the other man is the subject and my work is not

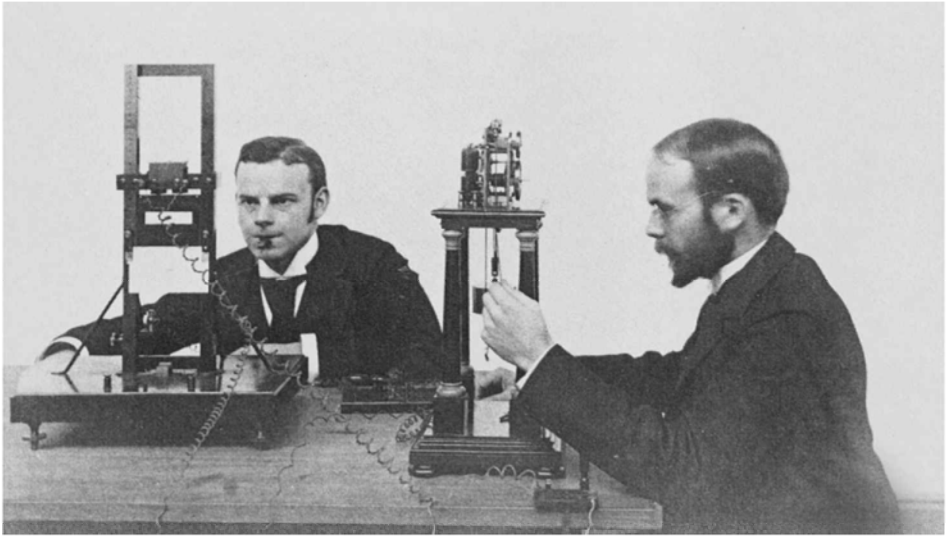


Figure 8. This photograph of the fall chronometer designed by Cattell during his Leipzig years shows a reaction-time experiment of the type Cattell and Berger performed by the hundreds. When the screen drops, the subject (left) is able to see a word written on a card. At the same time the chronoscope in front of the experimenter (right) starts running. As soon as the subject pronounces the word the lip-key in his mouth arrests the chronoscope, allowing the experimenter to read the reaction time. *Source: An Education in Psychology; James McKeen Cattell's Journal and Letters from Germany and England, 1880–1888*, edited by M.M Sokal (Cambridge, MA, 1981), 323.

especially difficult. So you see I only spend two hours in work that strains.'[54] Cattell worried in particular about the strain that the experiments involving visual stimuli like words, colours, or numbers would cause to his eyes. When using his new typewriter for the first time he is relieved to be able to write that 'One does not use the eyes at all, which of course is a special advantage to me'.[55]

Both the arrangement of the environment in which the experiment was to proceed, and the focus on an optimal moment of readiness, were aimed at achieving a certain *evenness* in the observer. Apart from the exclusion of diversion and strain, the state of the observer could also be steadied by *practice*. Practice, like calibration, is of a preparatory nature. Moreover, training must continue—like the calibration of instruments—until the subject's performance falls within a narrow range of variation. For the outcomes of trials to count as experimental data, both instruments and persons had to be finely tuned to their tasks. The two laboratory partners had to know their roles through and through. A prerequisite of experimental research at this time was that the observer understood the purpose as well as the procedure of the experiment.[56] Any kind of misunderstanding or mishandling could disturb the

[54] Ibid., p. 141.
[55] Ibid., p. 125.
[56] Understanding psychology had different functions for Wundt. It was crucial in his philosophy of science, in which he emphasized that the experimental subject ought not to be an utterly passive observer. On the contrary, it was crucial that the observer was a voluntary and knowledgeable participant. (This role did not, of course, preclude the need for preparation.) Besides being important in his philosophy of science, the requirement that the observer understood psychology was also strategically important to remain affiliated with the discipline of philosophy: mere experimenters could have no part of philosophy, well-educated and informed men of science could. See M. G. Ash, 'Experimental Psychology in Germany

outcome of the experiment. For this reason 'inexperienced persons, children or the insane, for example', were, as a rule, barred from participation. After practice and preparation, the observer could be taken as a point of access to what has been called 'a generalized mind'.[57] Being practised in appearing in experiments helped to make sure that the results were representative of the 'universal features of adult human mental life'.[58, 59] Viewing the subject as a generalized mind meant that experimenter and observer could switch roles between trials without affecting the format of the experiments. The unproblematic shifting of roles was further supported by the organization of Wundt's laboratory, with Wundt as a recluse theorist—a proper scientist—at the top and his advanced students and collaborators as interchangeable observers producing trustworthy data. Even Wundt could and did assume the role of a data-producing observer: indistinguishable from the others for the duration of an experiment. Along with the chronoscope, the control hammer, the chronograph, the tuning fork, the fall chronometer and whatever else was buzzing, ticking, or clicking during the trials, from the subject precision might emerge. As a means of producing matters of fact about the generalized mind, he was part and parcel of the material technology. A 'good' observer therefore was a highly specific type of individual, not to be found outside laboratory conditions. He brought to the experimental situation a well-trained mind, the result of practice, discipline, and control. Mental chronometry called for calibrated minds. Cattell and Berger were prepared to provide these.

Access to the generalized mind was facilitated by properly arranged experiments and supported by a certain amount of regularity *outside* the context of experimental practice. Cattell relates how he followed a strict scheme of physical exercise, which included fencing, tennis, football, skating, rowing, and riding. In his letters he often refers to his 'constant exercise'.[60] 'One day with me' he writes to his parents, 'is a repetition of the preceding, so that after I have told you what I do, for the following days I can simply write under it ditto, ditto, ditto. We made experiments of course this morning.'[61] After a long period of 'quiet, uneventful, regular work',[62] Cattell notes that the days begin to slip away in uniformity: 'one day is so much like another, and they all go so fast, that I am usually uncertain as to the day of the month, and must sometimes even count up to find the day of the week'.[63] In March 1885, approaching the end of his programme of experiments, he promises his parents that his letters after Easter will be more interesting and at all events 'won't contain the monotonous repetition, "we made experiments"'.[64] The monotonous repetition that may stifle

Before 1914: Aspects of an Academic Identity Problem', *Psychological Review*, 42 (1980), 75–86 (at p. 80). Nowadays in psychological research, the experimental subject is often kept in the dark about the specific research question guiding the experiment, and is not required to understand psychology and its concerns in a more general way. Ethical guidelines have been developed to protect subjects participating in experiments.

[57] Danziger (note 6).

[58] K. Danziger, 'Social Context and Investigative Practice in Early Twentieth-Century Psychology', in *Psychology in Twentieth-Century Thought and Society*, edited by M. G. Ash and W. R. Woodward (Cambridge, 1987), 13–33 (at p. 15).

[59] The demand for subjects who understood the purpose of experimentation in practice meant that psychologists or students of psychology were most eligible. The scientific schooling that was used as a selection criterion in a more general sense practically eliminated any female contribution to research of the human mind.

[60] *An Education in Psychology* (note 2), 138 and 141.

[61] Ibid., 143.

[62] Ibid., 168.

[63] Ibid., 142.

[64] Ibid., 166.

correspondence is essential to experimentation. It supports the evenness that is required of the observer and is ingrained in the order of the experiment.

7. Packages of precision

The culture of precision, constancy, and regularity that had reached into every nook and cranny of the Leipzig laboratory, and had got under the skin of both subjects and experimenters, quickly spread to new laboratories in other countries. The ideal of precision travelled far and wide, to academic laboratories in (primarily) the Western, industrialized world. 'We must admit that the rapid growth of psychology in America had been due to the conditions of the soil as well as to the vitality of the germ', Cattell observed.[65]

But how *does* precision travel?[66]

The dispersion of the Leipzig experimental customs involved people, instruments, and texts. As regards people, the foreign students, after receiving their PhD in Leipzig, returned home to found their own laboratories. Replicas of Wundt's laboratory appeared everywhere, as far away as Tokyo.[67] As many as 12 of the 43 laboratories existing in America in 1900 were established by students of Wundt's.[68] The ever-industrious Cattell started two of them: Pennsylvania (1887) and Columbia (1890). The cohort of researchers that received their PhD in the early years of the Leipzig laboratory—among them, Cattell (1886), Angell (1891), Scripture (1891), and Titchener (1892)—gave the first generation of psychologists a distinctly Wundtian touch. As to instruments, the apparatus for the new laboratories was ordered from the Leipzig laboratory technician Carl Krille, selected from the Zimmermann catalogue, or copied by local instrument makers from the technical descriptions and detailed prints in Wundt's *Grundzüge* and the *Philosophische Studien*. Over a third of the experimental machinery in the Harvard laboratory came from Leipzig; in other laboratories too the basic equipment was often imported from Germany. These brass-and-mahogany packages of precision travelled the world, establishing the status of psychology as a hard science along the way. We now turn to texts. One could study the intricacies of the apparatus, and the proper way to set up an experiment, by consulting the Zimmermann catalogue, which would refer to the relevant passages in the *Grundzüge*, which would refer to research described in the *Philosophische Studien*, which, of course, would refer to the catalogue; a perpetual and productive cycle indeed.

Every element in the distribution of precision—instruments, texts, and people—could be moved separately, but only worked in combination. In order to be

[65] J. McK. Cattell, 'Address of the President before the American Psychological Association, 1895', *Psychological Review*, III (1896) 134–48 (at p. 135). Cattell's clever characteriatizon of the susceptive conditions of the soil should not blind us to the differences between conditions in different disciplines or countries. On psychology as it moved from Germany to the United States, see, for example, several chapters in *The Problematic Science: Psychology in Nineteenth-Century Science*, edited by W. R. Woodward and M. G. Ash (Praeger, 1982) and in Ash and Woodward 1987 (see note 58).

[66] On the trials and tribulations of making precision travel, see for example M. N. Wise. 'Precision: Agent of Unity and Product of Agreement. Part 1—Traveling', in Wise (note 4), 92–100; B. Latour, 'Visualization and Cognition, Thinking with Eyes and Hands', in *Knowledge and Society*, *Studies in the Sociology of Culture Past and Present*, vol.6 (Greenwich, CT, 1986), 1–40; J. O'Connell, 'Metrology: The Creation of Universality by the Circulation of Particulars', *Social Studies of Science*, 23 (1993), 129–73.

[67] A. L. Blumenthal, 'A Re-appraisal of Wilhelm Wundt', *American Psychologist*, 30 (1975), 1081–8.

[68] C. R. Garvey, 'List of American Psychological Laboratories', *Psychological Bulletin*, 26 (1929), 652–60.

performed elsewhere, the elements of the reaction-time experiment Leipzig-style had to be reassembled. The roles of experimenter and subject could be practised during rehearsals, directed by a Wundtian, preferably in Leipzig; the scenario could be studied in manuals and textbooks; the props and the set could be ordered or copied. The chronometric regime distinguished itself by an order that included people who were inextricably connected to the instrumentation and its description. Together they forcefully proclaimed the chronometrical code. The demand for precision ignored the difference between goals and means, humans and machines. The publications, the properly trained psychologists, and the instruments all incorporated the trustworthiness of the knowledge produced in experimental practice. While their cooperation was a prerequisite for the validity of the experiment, it could not fully control the way this would be implemented elsewhere. Access to the generalized mind was only possible if both subject and experimenter inserted themselves into the chain of instruments. But what that chain would look like after transportation was anybody's guess.

The precision that permeated the Leipzig laboratory was supported by arguments and descriptions that enlarged susceptibility to the Leipzig style of precision. Two years after securing his PhD from Wundt, Edward Scripture, director of the Yale laboratory, delivered a speech to the American Psychological Association.[69] His theme was precision in psychology, his tone pedagogical, his opening alarmed: American psychologists make experiments without attending to even the most fundamental laws of scientific experimentation. They vary several conditions simultaneously, use instruments without having a clue about their construction, and make measurements without realizing there is such a thing as a science of measurement. New laboratories are emerging everywhere, and every year there are more, yet almost all of the research with any real scientific substance comes from two or three labs alone. Why, Scripture wonders, do American psychologists not take a leaf out of Wundt's book? In Leipzig, year after year measurements are made 'with ever increasing accuracy and with the continual discovery of unsuspected facts'.[70] Topics that at first could only be explored qualitatively are brought within reach of exact experimentation; in Leipzig 'the fact is always kept in mind that each subject taken up should be pushed forward from time to time, ever a little further into the domain of accuracy'.[71] The Yale laboratory considered itself to be a part of this tradition of precision and trustworthiness. In our laboratory, Scripture continues, the Hipp chronoscope—with its mean variation of one millisecond—has been replaced by a graphic method developed 'to such a degree that we can make and count records of any desired accuracy with less work than with the Hipp chronoscope'.[72] An alarm thermostat placed beside the tuning fork keeps the error due to changes of temperature below one-thousandth of a second. And, of course, only trained observers are used: 'You would not put a car-driver to seeking double stars with the Lick telescope'.[73] Anything that might cause errors and variation must be located and eradicated in order to attain 'accuracy and trustworthiness'.[74]

America had to be schooled in precision, and in this process Leipzig shone the guiding light. Wundt was well aware of this. In an 1893 note in the *Philosophische*

[69] E. W. Scripture, 'Accurate Work in Psychology', *American Journal of Psychology*, VI (1893), 427–30.
[70] Ibid., p. 428.
[71] Ibid., p. 428.
[72] Ibid., p. 429.
[73] Ibid., p. 429.
[74] Ibid., p. 428.

Studien, he related how colleagues often approach him, eager to find out how they might obtain apparatus for research and demonstrations.[75] He would refer them to his instrument maker, Krille, who could provide many of the instruments himself and who had chronoscopes on offer, via a connection with the Hipp factory. Wundt added that Krille in some cases made small alterations to the apparatus—sometimes at the customer's instigation, sometimes on his own account. Therefore, it could not be guaranteed that the instrument ordered by its usual name was in fact exactly the same as the one used in Leipzig. Wundt goes on to assume that his colleagues would much prefer to have the very same instruments as they have in Leipzig, and is willing—'im Interesse der Sache'—to test the apparatus produced by Krille in his laboratory before transportation. After the test, the items of apparatus could then be provided with a certificate 'confirming their essential similarity to the apparatus used here'.[76] Wundt's generous offer to cast his expert eye on the instruments before they travelled abroad shows once more how local Leipzig standards did not automatically become the worldwide criterion for experimental research. The distribution of precision required regulation, stimulation, and surveillance.

8. 'An important factor seemed to be susceptible to measurement'

In the introductory pages of 'On the speed of mental processes', Donders had allowed himself a philosophical digression on the relation between physiology and consciousness. Physiology, Donders reflected, is a science of quantitative measurement. The phenomena of the human mind, on the other hand, 'can neither be measured nor evaluated, and we know no unit by which to express sensation, reason and will in figures'.[77] This would seem to preclude the exact measurement of mental processes altogether. Donders continued, however, with a surprising twist: 'But will all quantitative treatment of mental processes be out of the question then? By no means! An important factor seemed to be susceptible to measurement: I refer to the time required for simple mental processes.'[78]

This idea, that time opens up the human mind for measurement, became something of a topos in psychological literature. In Cattell's estimation the findings of experimental psychology 'proved those to be wrong who with Kant hold that psychology can never become an exact science'.[79] For the cohort of psychologists to which Cattell belonged, their science was to be a sort of 'physics of consciousness', in search of a 'mental mechanics'.[80] Cattell indicated a methodological parallel between both sciences: 'As Experimental Physics is devoted to the measurement of time, space and mass in the material world, so Experimental Psychology may measure time, complexity and intensity in consciousness.'[81] Since the measurement of time is

[75] W. Wundt, 'Notiz über psychologische Apparate', *Philosophische Studien*, VIII (1893), 655–6.
[76] Ibid., 656.
[77] Donders, 1969 (note 13), 413.
[78] Ibid., 413.
[79] J. McK. Cattell, 'The Time it Takes to See and Name Objects', *Mind*, XI (1886), 63–5 (at p. 63).
[80] J. McK. Cattell, 'Psychology at the University of Pennsylvania', *American Journal of Psychology*, III (1891), 281–3 (at p. 281).
[81] Ibid., 281. In the privacy of his correspondence Cattell expressed the idea that psychology, as a science, was superior to physics. From a letter to his parents on 4 February 1885 (note 47): 'Science has always solved the easiest questions first. Astronomy and physics were well advanced before chemistry and geology were thought of, then came physiology and biology, last of all psychology. Psychology is of course the most important of the sciences—all science and all knowledge depends on the nature of the human mind' (p. 159).

the connecting term in this analogy, one should not be surprised to find that psychologists who wished to present their discipline as a natural science singled out the programme of mental chronometry as a paragon of exactness.

In the historiography of psychology, rhetorical manoeuvres like these are routinely taken as efforts aimed at legitimization. Psychologists, 'insecure because of their unscientific heritage from philosophy', as an early phrasing of this argument runs, strategically emphasized the exact status of their methods and instruments.[82] By associating with one of the established sciences—physics, physiology, astronomy—psychologists hoped to share in the prestige these disciplines had already earned. Psychology's methodological and technical preoccupation fits in nicely with this line of reasoning.[83] The irony of the matter, however, is that psychologists involved in the incessant refinement of time measurement ended up by producing procedures which were far beyond the metrological routines in the very same natural sciences which served them as a model. In ordinary physics, standards of precision at the level of one-thousandth of a second, although theoretically attainable, served a purpose in isolated instances only.[84] Even in psychology itself there was no use for this kind of precision. Ludwig Lange, whose control apparatus was designed to calibrate the chronograph to a tenth of a millisecond, had to admit that a greater accuracy than one millisecond was 'seldom necessary'; his efforts to increase this level of precision by a factor of ten, he added, were best seen as a somewhat doubtful investment in future research: 'sooner or later, here or there, it may become necessary'.[85] Unfortunately for Lange, this 'sooner or later, here or there' was never reached in the century of psychology ahead of him: the data on contemporary mental chronometry are still reported in milliseconds.

In the case of mental chronometry, then, the very same procedures that began as a form of strategic imitation came to indicate a *difference* between psychology and physics. More fundamental, however, is a second unexpected consequence of the distribution of precision measurement in mental chronometry.

The metrological conventions in the technology for time measurement supplied psychologists with a criterion of precision that travelled well. This criterion was linear: an instrument registering reactions in thousandths of seconds was deemed more precise than an instrument measuring in hundredths of seconds. The attempts to construe similar criteria for the 'social technology' of reaction-time experiments proved less easily transportable. For the subject's state of 'attentive readiness', the proper amount of concentration, the optimal number of trials in each experiment, only local and temporary norms emerged. No authoritative decree as to how fast the trials should succeed one another or how often experimenter and subject should switch roles was issued. In fact, the measurement of time appeared to be the *only* aspect of the experimental situation that lent itself to a transportable judgement against a consensual criterion. For the programme of mental chronometry, it soon became clear, this was not sufficient.

[82] E. G. Boring, 'The Beginning and Growth of Measurement in Psychology', in *Quantification: a History of the Meaning of Measurement in the Natural and Social Sciences*, edited by H. Woolf (Indianapolis, 1961) 108–27 (at p. 124).

[83] Schaffer makes an even stronger claim: he argues that the disciplining of subjects in psychology was inspired by the practice in astronomy, where individual observers obeyed a similar discipline in order for the observations to become comparable. Schaffer, 1988 (note 10).

[84] One such instance would be the manufacture of photocameras, where the shutter time had to be determined in milliseconds. U. Tillmanns, *Geschichte der Photographie* (Stuttgart, 1981).

[85] Note 21, 459.

In the early 1890s, reaction-time experiments conducted in the newly established laboratories began to yield a flood of data and findings—as well as a nasty complication. Experiments in different laboratories, with apparently identical experimental arrangements, produced results showing gross discrepancies. The size of these discrepancies was not reduced by measuring them in milliseconds; on the contrary, precision measurement emphasized the differences. In some cases the deviations in the results were caused by individual differences between subjects or by other identifiable factors.[86] Yet there was also a persistent residue of variation that seemed to escape all manipulation.[87] This residue—and here we come up against a second paradox—was brought out by the attempts to impose more constancy on the experimental situation.

That constancy was of the greatest importance in mental chronometry was undisputed. The problem, however, was that constancy could be pursued in a thousand different ways, resulting in its opposite: variation. One of the most radical attempts to achieve constancy may serve as an illustration. In his APA address on accuracy in psychology Scripture presented a minute description of the way his lab, in an attempt to emulate Wundt's practice in Leipzig, had come to handle experimental subjects:

> Of course, the experimenter, the recording apparatus and the stimulating apparatus are in a part of the building distant from the person experimented upon. He sits in the reacting room perfectly alone, knowing nothing of what is going on. The warning click of a sounder tells him to concentrate his attention; a click occurs in the telephone, or a Geissler tube flashes out, or an electric shock pricks the skin; he reacts in response and all is again quiet. All light and moving objects are, of course, excluded. Dr Bliss's experiments have shown that a steady light of moderate intensity causes no distraction; we may consequently at the present stage of accuracy have the room lighted up by an incandescent lamp, if the observer is made more comfortable thereby. Disturbing sounds are probably the worst sources of error; their exclusion has been a difficult problem, but we have solved it by our isolated room. The distractions due to insufficient ventilation, changing temperature, changing barometric pressure and changing humidity have not yet been eliminated, but the arrangements thereto have been made and will be completed before long.[88]

In the Yale laboratory the experimental subject was an instrument, requiring a physical environment not unlike that in which the Metre of Paris was kept. Yet, if one compares Scripture's prescriptions for handling the subject with Cattell's description of the circumstances of his experiments with Berger, one cannot fail to conclude that two researchers, both obsessed with constancy, precision, and regularity, arranged

[86] In the context of early mental chronometry, individual differences were seen as a source of disturbance. In later psychological research, for instance on reaction times of men, women, children, or certain categories of psychiatric patients, these differences became the object of study.

[87] The persistent residue of variation calls to mind the accidental errors appearing in the treatment of experimental data, in particular in physics. Accidental errors, 'were unpredictable…and hence truly "accidental", a word that also suggested the investigator's ignorance, or incomplete knowledge of them' and were distinguished from constant errors, which included 'imperfections of the senses and instruments [that] created regular quantitative variations in measurements'. The latter 'could be estimated or calculated and then analytically eliminated' (note 9), 108. In our case, rather than estimating or calculating, the experimentalists are concerned with the arrangement of the experimental situation, the instruments and people in them.

[88] Note 69, 429.

the conditions of their experiments in completely different ways. As much as Scripture—and Cattell before him—tried to present his instructions as a set of natural, obvious experimental precautions, to be respected by any competent researcher, in the practice of mental chronometry each laboratory developed its own conventions.[89]

In 1886, Cattell concluded the last of his three *Mind* articles on mental chronometry with the satisfied statement that his experiments had shown that the human mind could indeed be subjected to the rigorous and exact methods of science. He and his fellow researchers had succeeded in determining the duration of a wide range of mental processes. These times, Cattell wrote, turned out to be constants: 'they are no more arbitrary, no less dependent on fixed laws than, for example, the velocity of light'.[90] This reference to the constancy of physical laws was ominous. Ten years after the hopeful beginnings of the chronometric programme little remained of the constancy of the 'generalized mind'. Towards the mid-1890s it had become clear that the concerted efforts to calibrate the experimental situation had resulted in the very opposite of what one had hoped to achieve. Each laboratory published a different numerical outcome for one and the same psychological process—albeit accurate to the millisecond.[91]

Should we say, then, that what was travelling in the network of academic psychology was the *ideal* of precision, and that precision itself never reached its destination? It would be more accurate, we feel, to conclude that the very success of the chronometric code revealed its limits.

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[89] Scripture, Titchener, and Whipple, for example, published manuals in which they described the proper conduct in a psychological laboratory. The experimental etiquette was spelled out meticulously, but varied widely from author to author. E. W. Scripture, *The New Psychology* (London, 1897); E. B. Titchener, *Experimental Psychology; A Manual of Laboratory Practice* (New York, 1901–5); G. M. Whipple, *Manual of Mental and Physical Tests* (Baltimore, 1910). Derksen explores the particular way in which Heymans, the 'Dutch Wundt', organized his laboratory. M. Derksen, 'Are we not Experimenting then? The Rhetorical Demarcation of Psychology and Common Sense', *Theory* & *Psychology*, 7 (1997), 435–56.

[90] Note 50, 538.

[91] E. G. Boring, *A History of Experimental Psychology* (New Jersey, 1950), 2nd edn, 149.