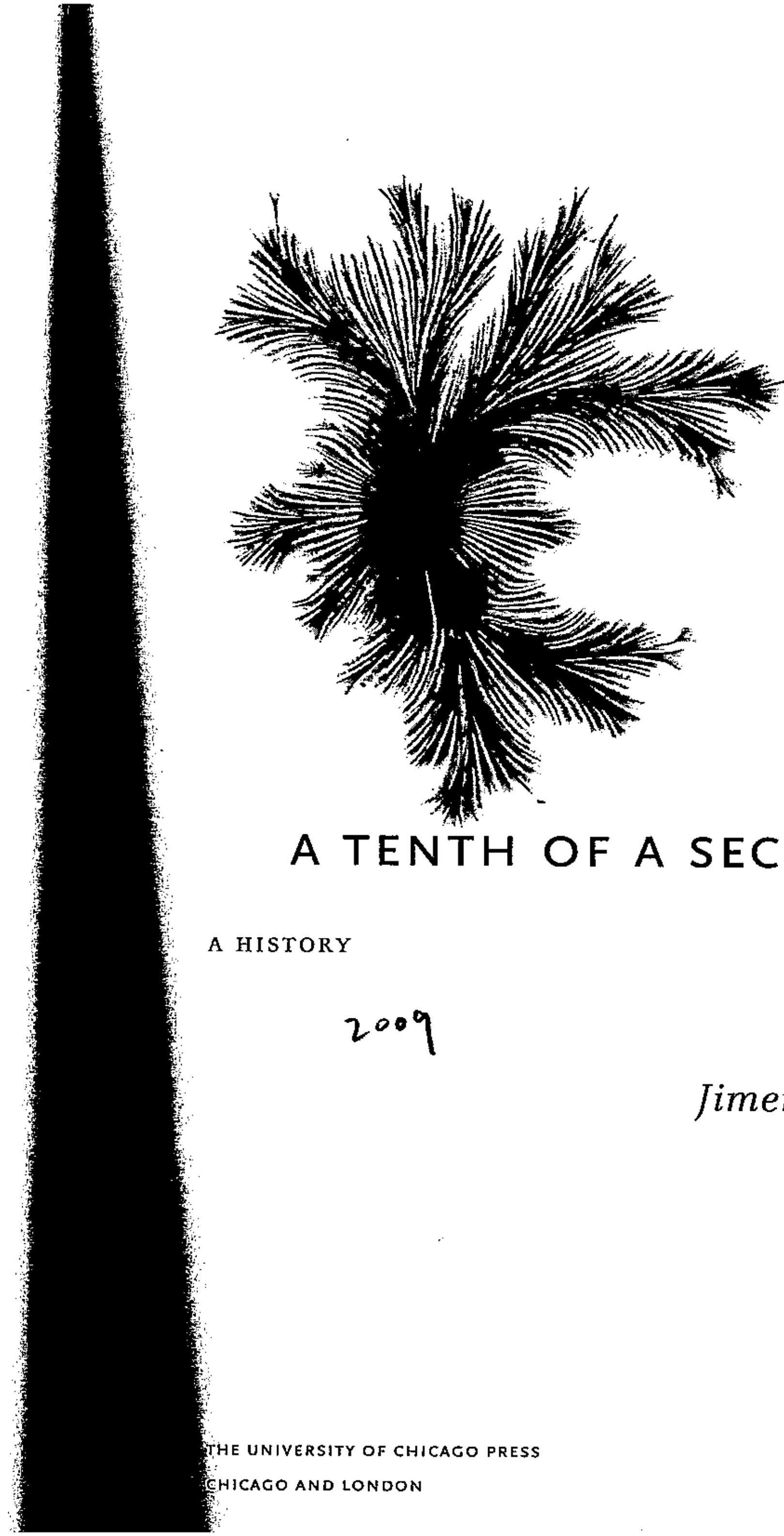

A TENTH OF A SECOND

A HISTORY

2009

Jimena Canales

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To my mother, Rocío, and to my son, Billy.

CHAPTER 2

REACTION TIME AND THE PERSONAL EQUATION

We should always remember the famous case of the Astronomer Royal, Nicholas [*sic*] Maskelyne, who dismissed his assistant Kinnebrook for persistently recording the passage of the stars more than half a second later than he, his superior.

MICHAEL POLANYI, chemist and philosopher

A widely read and influential text by the famous psychologist and historian of psychology Edwin G. Boring (1929) described a century-long obsession with the "sacred 0.1 sec."[1] When did this value first appear as a "sacred," salient, and troubling, time period? According to Boring, the incident that triggered this devotion was well known to "every psychologist."[2] The date was 1796, and the place was the Royal Observatory in Greenwich. That year David Kinnebrook, an assistant to the British and Royal Astronomer Nevil Maskelyne, was fired because his observations systematically differed from those of his superior.[3] An influential author writing decades after Boring was

1. Edwin G. Boring, *A History of Experimental Psychology* (New York: Appleton-Century-Crofts, 1929), 148.
2. Ibid.
3. For repetitions of the Maskelyne incident see Rodolphe Radau, "Sur les erreurs personnelles," *Le Moniteur scientifique* 7 (1865): 977; Etienne-Jules Marey, "Leçon d'ouverture: Vitesse des actes nerveux et

even stricter about its historical origins: "Any history of the personal equation in astronomy *must necessarily* begin" at that time.[4] In *Personal Knowledge* (1958), the famous chemist and philosopher Michael Polanyi commenced his account of science with this same sage tale: "We should always remember the famous case of the Astronomer Royal, Nicholas Maskelyne, who dismissed his assistant Kinnebrook for persistently recording the passage of the stars more than half a second later than he, his superior."[5]

The tenth of a second was closely associated with the discovery of the personal equation in astronomy and reaction time in experimental psychology. Its history thus forms part of a "standard account" of the history of experimental psychology that has been repeated for more than a century.[6]

The personal equation and reaction time were two controversial terms whose exact meaning would be debated for decades. The term "reaction time" was mostly used by experimental psychologists to describe a lag time, of the order of the tenth of a second, between stimulus and response; the term "personal equation" was mostly used by astronomers. Different astronomical observers assessed time differently, and while these assessments showed a remarkable constancy within the same person, when individuals were compared against each other, results often varied by a few tenths of a second. Many astronomers believed that one reason why observers differed in these estimations was due to their different times of reaction. As

cérébraux.—Le Vol dans la série animale, Collège de France, histoire naturelle des corps organisés, cours de M. Marey," *Revue scientifique* 6, no. 4 (26 December 1868): 62; Sigmund Exner, "Experimentelle Untersuchung Der Einfachsten Psychischen Processe. Erste Abhandlung: Die Persönliche Gleichung," *Archiv für die gesammte physiologie des menschen und der thiere, herausgegeben von Dr. E. F. W. Pflüger* 7 (1873): 602. Henri Beaunis, *Nouveaux éléments de physiologie humaine comprenant les principes de la physiologie comparée et de la physiologie générale* (Paris: J.-B. Baillière et fils, 1876), 1030; Etienne-Jules Marey, *La Méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine* (Paris: G. Masson, 1878), 144; Henri Beaunis, *Nouveaux éléments de physiologie humaine comprenant les principes de la physiologie comparée et de la physiologie générale*, 2nd ed. (Paris: J.-B. Baillière et Fils, 1881), 2:1363, and *Nouveaux éléments de physiologie humaine comprenant les principes de la physiologie comparée et de la physiologie générale*, 3rd ed. (Paris: J.-B. Baillière et fils, 1888), 2:801; A. Rémond, *Recherches expérimentales sur la durée des actes psychiques les plus simples et sur la vitesse des courants nerveux à l'état normal et à l'état pathologique* (Paris: Octave Doin, 1888), 11; Edmund C. Sanford, "Personal Equation," *American Journal of Psychology* 2 (1889): 8; Joseph Jastrow, *The Time-Relations of Mental Phenomena*, Fact and Theory Papers (New York: N. D. C. Hodges, 1890), 21; Paul Fraisse, "The Evolution of Experimental Psychology," in *History and Method*, ed. Jean Piaget, Paul Fraisse, and Maurice Reuchlin, vol. 1 of *Experimental Psychology: Its Scope and Method*, ed. Jean Piaget, Paul Fraisse, and Maurice Reuchlin (New York: Basic Books, 1968).

4. Raynor L. Duncombe, "Personal Equation in Astronomy," *Popular Astronomy* 53 (1945): 2–13, 63–76, 110–21. Italics mine.

5. Michael Polanyi, *Personal Knowledge* (Chicago: University of Chicago Press, 1958), 19–20.

6. Boring, *A History of Experimental Psychology*, 133. Some examples are Fraisse, "The Evolution of Experimental Psychology"; G. P. Brooks and R. C. Brooks, "The Improbable Progenitor," *Journal of the Royal Astronomical Society of Canada* 73 (1979). For a critique of the "standard account," see Christoph Hoffmann, *Unter Beobachtung: Naturforschung in der Zeit der Sinnesapparate* (Göttingen: Wallstein Verlag, 2006).

the terms reaction time and personal equation gained currency, their definitions nonetheless remained in flux well into the twentieth century.

One of the first attempts to differentiate their meaning came from the famous Viennese scientist Sigmund Exner, who in the 1870s, coined the phrase "reaction time" to distinguish it from "personal equation," "personal time," "personal error," and "individual differences."[7] Yet scientists after Exner continued to debate and argue about their differences and similarities. What is more, the use of these terms often exceeded the boundaries of science, affecting philosophy. They even became labels for biases, prejudices, and personal subjectivities.

The unfair dismissal of Kinnebrook by Maskelyne showed how excessive power could corrupt knowledge. The incident became a rallying symbol of a small but sturdy revolutionary movement within science whose goals echoed those of the larger European revolutions. The story was told using politically charged language. It was (so the story went) a moment when the authoritarian Astronomer Royal unfairly repressed his assistant's unique way of seeing. Tenth-of-a-second differences could only be acknowledged in scientific spaces organized differently, where subordinate observers were not so easily dismissed. According to some, the lesson to be drawn from this incident was that science, like society, was also hurt by authoritarian regimes. Excessive power marred scientific results. In France, it challenged the ideals of *égalité, fraternité,* and *liberté* in national and local terms. Certain scientists of dangerous Napoleonic ilk, such as Urbain Le Verrier, director of the Paris Observatory during the second half of the century, and Jean-Martin Charcot, the expert in hysteria who influenced a generation of psychologists, threatened these values. A group of rebellious scientists rose against their superiors, advocating new scientific practices characterized by friendly and exchangeable roles between astronomers and observers and subjects and experimenters. They stressed the benefits of new laboratory-oriented practices characterizing an emergent discipline that they came to name "experimental psychology." This new field stood in sharp contrast to traditional clinical psychology, where dismal power differentials existed between scientists such as Charcot, his mostly female patients, and even his students and colleagues.

7. Sigmund Exner, "Experimentelle Untersuchung der einfachsten psychischen Processe. Erste Abhandlung: Die persönliche Gleichung," *Archiv für die gesammte Physiologie des Menschen und der Thiere, herausgegeben von Dr. E. F. W. Pflüger* 7 (1873): 608–9. See also Sigmund Exner, "Experimentelle Untersuchung der einfachsten psychischen Processe. Zweite Abhandlung: Ueber Reflexzeit und Rückenmarksleitung," *Archiv für die gesammte Physiologie des Menschen und der Thiere, herausgegeben von Dr. E. F. W. Pflüger* 8 (1874): 526–37.

Histories of the astronomers' discovery of the personal equation conveyed various lessons. Connected to social and political ideals, scientists claimed that this moment marked the beginning of a new era, where the philosophies of Descartes and Kant would finally be surpassed, where scientific materialism would eliminate the last vestiges of religious irrationality, and where new forms of political representation reigned supreme.[8] The "standard account" was particularly important because it was a parable demonstrating a balanced (neither too excessive nor too narrow) use of measurement in modernity.

While debates about the significance and meaning of the personal equation and reaction time concerned much more than experimental psychology and astronomy, historians have nonetheless focused on them through the lenses of these two disciplines. They have also given a consistent view of their origin.

The "Standard Account" from Bessel to Wundt

According to the "standard account," the Prussian astronomer Friedrich Bessel was the first scientist after Maskelyne to study the personal equation, starting in 1815.[9] Investigations then remained dormant for a number of years, partly due to a longstanding belief in the impossibility of measuring the speed of sensory transmission. Johannes Müller, the doyen of German physiology, considered the speed of nerve transmission to be immeasurable. In the *Elements of Physiology* (1844), he explained:

> The attempts made to estimate the velocity of nervous action have not been founded on sound experimental procedures. Haller calculated that the nervous fluid moved with the velocity of 9,000 feet in a minute; Sauvages estimated the rate of its motion at 32,400, and another physiologist, at 57,600 million feet in a second. . . . We shall probably never attain the power of measuring the velocity of nervous action; for we have not the opportunity of comparing its propagation through immense space, as we have in the case of light.[10]

8. For recent work on reaction time experiments and French experimental psychology see Henning Schmidgen and Jacqueline Carroy, "Reaktionsversuche in Leipzig, Paris und Würzburg: Die deutsch-französische Geschichte eines psychologischen Experiments, 1890–1910," *Medizinhistorisches Journal* 39 (2004); Jacqueline Carroy, "Théodule Ribot et la naissance d'une psychologie scientifique," in *L'Anhédonie: Le Non-Plaisir et la psychopathologie*, ed. M.-L. Bourgeois (Paris: Masson, 1999); Jacqueline Carroy and Régine Plas, "The Origins of French Experimental Psychology: Experiment and Experimentalism," *History of the Human Sciences* 9, no. 1 (1996): 77.

9. The original is Wilhelm Friedrich Bessel, "Personal Gleichung," *Astronomische Beobachtungen* 8 (1822).

This state of affairs started to change in the 1850s, when the German scientist Hermann von Helmholtz and the physiologist Emil du Bois-Reymond compared the nervous agent to electricity and assigned a finite speed to both.[11] Their canonical experiments overturned the longstanding belief in the instantaneity of nerve transmission. In the following decades, an increasing number of scientists started comparing the nervous system to emerging telegraph networks.[12]

Helmholtz and du Bois-Reymond argued that delays in nerve transmissions overwhelmed physical quantities by their magnitude. While physicists thought they were competently dealing with speeds of more than 400 million meters per second, they often ignored that their own organisms functioned at a much slower speed of 26–30 meters per second. By refusing to consider physiological elements, they argued, scientists introduced enormous errors into their results. Among their examples, they included experiments on the speed of electricity, light, sound, and the velocity of the earth, as well as mundane examples of speeding horses—of military, commercial, scientific, and artistic concern. Even astronomers, they insisted, could "profit" from the findings of physiologists.

After intially working with frogs, Helmholtz suggested, but never entirely succeeded in, a way to extend his spectacular research to humans. From his examinations of humans, he concluded that "the quickness of reflection is . . . by no means so great as seems to be assumed in the expression

10. Johannes Müller, *Elements of Physiology*, 2 vols., trans. William Baly (London: Taylor and Walton, 1838–42), 729. Originally published as Johannes Müller, *Handbuch der Physiologie des Menschen* (Coblentz: Hölscher, 1834), 1:581.

11. For Helmholtz's work with frogs and the graphic method, see Frederic L. Holmes and Kathryn M. Olesko, "The Images of Precision: Helmholtz and the Graphical Method in Physiology," in *The Values of Precision*, ed. M. Norton Wise (Princeton, N.J.: Princeton University Press, 1995); Kathryn M. Olesko and Frederic L. Holmes, "Experiment, Quantification, and Discovery: Helmholtz's Early Physiological Researches, 1843–50," in *Hermann von Helmholtz and the Foundations of Nineteenth-Century Science*, ed. David Cahan (Berkeley: University of California Press, 1993); Robert M. Brain, "The Graphic Method: Inscription, Visualization and Measurement in Nineteenth-Century Science and Culture" (Ph. D. thesis, University of California, Los Angeles, 1996); Robert M. Brain and M. Norton Wise, "Muscles and Engines: Indicator Diagrams and Helmholtz's Graphical Methods," in *The Science Studies Reader*, ed. Mario Biagioli (New York: Routledge Press, 1999).

12. For comparisons between telegraph networks and the nervous system, see Christoph Hoffmann, "Helmholtz' Apparatuses: Telegraphy as a Working Model of Nerve Physiology," *Philosophie Scientiae* 7 (2003); Iwan Rhys Morus, "'The Nervous System of Britain': Space, Time and the Electric Telegraph in the Victorian Age," *British Journal for the History of Science* 33 (2000).

Considérations suggérées par les résultats précédents. — La table suivante offre l'occasion de comparer la vitesse de l'agent nerveux, telle qu'elle a été établie par les recherches précédentes, avec celle de plusieurs autres agents ou corps en mouvement, et l'on peut tirer de cette comparaison plusieurs conclusions intéressantes :

Vitesse de	Mètres en une seconde.
Électricité (expériences de M. Wheatstone)...	464 000 000
Lumière...	300 000 000
Son dans le fer...	3 485
— dans l'eau...	1 435
— dans l'air...	332
Étoiles filantes...	64 380
Terre dans son orbite autour du soleil...	30 800
Surface de la terre à l'équateur...	465
Boulet de canon...	552 (1)
Vent...	1—20
Vol de l'aigle...	35 (2)
Locomotive...	27
Levrier, cheval de course...	25

Figure 2.1. Chart of common velocities against which du Bois-Reymond compared the speed of nerve transmission. From Emil du Bois-Reymond, "Vitesse de la transmission de la volonté et de la sensation à travers les nerfs: Conférence de M. du Bois-Reymond à l'Institution Royale de la Grande-Bretagne," *Revue scientifique* 4, no. 3 (15 December 1866): 33–41, on p. 38.

'quick as thought.'"[13] A commentator on his work remarked how "under the most favorable conditions and with a highly sustained attention, the brain needs at least 0.1 seconds for transmitting its orders to the nerves which conduct voluntary movements."[14]

In the eyes of physiologists, Helmholtz's work heralded a new physicalism that displaced a vitalism based on the concept of the *Lebenskraft* or "life force." For physicists, his research on the conservation of force was equally revolutionary. They claimed it as one of the pillars of the new science of thermodynamics. Helmholtz's results soon became world famous. A commentator explained the implications of his research. If the personal equation was related to the speed of thought, and if it could be reduced through

13. Hermann von Helmholtz, "Ueber die Methoden, kleinste Zeittheile zu messen, und ihre Anwendung für physiologische Zwecke," *Königsberger Naturwissenschaftliche Unterhaltungen* 2 (1851): 325, and "On the Methods of Measuring Very Small Portions of Time, and Their Application to Physiological Purposes," *The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science* 4 (1853): 189.
14. Otto Eduard Vincenz Ule, "Sur les moyens de mesurer la pensée: Lettre de M. Ule à M. E. Desor," *Revue suisse* 20 (1857).

education, could someone become more intelligent through practice and discipline?[15] By the second half of the century many others scientists, first among them the astronomer Adolph Hirsch and the ophthalmologist Rudolf Schelske, tried to eke graphic images of nerve impulses from creatures other than amphibians.[16]

In 1868 the preeminent Dutch physiologist and ophthalmologist Franciscus Cornelis Donders took these investigations to a new level.[17] He became known as the first person to measure the duration of mental acts along with his student Johan Jacob de Jaager.[18] Donders and his student offered a number for the speed of thought—amounting to approximately a tenth of a second—and claimed for themselves the honor of having been the first to measure it. They criticized previous investigators, such as Johannes Müller, for viewing "the time within which a message is transmitted from the periphery to the spinal chord and the brain or from there to the muscles as infinitesimal."[19] In a famous publication provocatively titled "On the Speed of Mental Processes" (1868), Donders argued that "the mental process of conception and expression of the will lasts less than 1/10 of a second."[20]

Donders's work soon became known in France through "journals and scientific publications" that "have recently recounted the presentation of M. Donders of the Utrecht Academy of two extremely interesting instruments."[21]

15. The letter, written by the German theologian, politician and scientific writer Otto Ule, was sent to the geologist Eduard Desor, friend of the renowned naturalist Louis Agassiz and a prime force in establishing Hirsch's Observatory and Hipp's telegraph and electric clock factory. Ibid. "What prevents us from developing the organ of our intelligence through sound and sustained exercise? Why not aspire to virtuosity in the art of thought, from the moment it is demonstrated that it does not depend only on individual capacities, but that it can be the product of education and exercise?" Ibid., 202.
16. For these early attempts see Jimena Canales, "Exit the Frog, Enter the Human: Physiology and Experimental Psychology in Nineteenth-Century Astronomy," *British Journal for the History of Science* 34 (June 2001).
17. F. C. Donders, "La Vitesse des actes psychiques," *Archives Néerlandaises* 3 (1868). For recent work on Donders, see Henning Schmidgen, "The Donders Machine," *Configurations* 13 (2005): 211–56.
18. While Helmholtz had lamented that reaction time was related to the speed of thought, they found this relation extraordinarily interesting. De Jaager cited Helmholtz's claim that reaction time measurements "suffer from the unfortunate fact that part of the measured time depends on mental processes." Cited in Johan Jacob de Jaager, "Introduction," in *Origins of Psychometry: Johan Jacob de Jaager, Student of F. C. Donders on Reaction Time and Mental Processes (1865)*, ed. Josef Brožek and Maarten S. Sibinga, Dutch Classics in the History of Science (Nieuwkoop: B. de Graaf, 1970), 16.
19. Johan Jacob de Jaager, "Reaction Time and Mental Processes," in *Origins of Psychometry: Johan Jacob de Jaager, Student of F.C. Donders on Reaction Time and Mental Processes (1865)*, ed. Josef Brozek and Maarten S. Sibinga (Nieuwkoop: B. de Graaf, 1970), 43.
20. F. C. Donders, "On the Speed of Mental Processes," in *Attention and Performance II: Proceedings of the Donders Centenary Symposium on Reaction Time*, ed. W. G. Koster (Amsterdam: North Holland, 1969), 418.
21. Ramon de la Sagra, "Académie des sciences: Séance du lundi 1er février," *Les Mondes: Revue hebdomadaire des sciences et de leurs applications aux arts et à l'industrie par M. l'abbé Moigno* 19 (1869): 213. Donders's work was reprinted in F. C. Donders, "Deux instruments pour la mesure du temps nécessaire pour les actes psychiques (Extrait des Archives Néerlandaises)," *Journal de l'anatomie et de la physiologie normales et pathologiques de l'homme et des animaux* 5 (1868).

A few years after his investigations, the German psychologist Wilhelm Wundt instituted reaction time research in his Leipzig laboratory. The "standard account" of the history of reaction time and the personal equation designated Wundt as the founder of experimental psychology and described it as a characteristically German discipline.[22] To this day, his reaction time experiments are still widely considered the *crucial experiments* demonstrating that mental processes are measurable and quantifiable.

The second half of the nineteenth century was marked by a burst of new research in these topics. Personal equation experiments in astronomy were accompanied by analogous investigations by physiologists and psychologists. Many scientists in France and elsewhere publicized numbers for the speed of nerve transmission not only in animals, but also in humans. Their investigations expanded from studying motor nerves in severed body parts to studying sensory nerves in living subjects. They switched from measuring the speed of sensory transmission to determining the duration of mental acts. Various instruments came into use: Pouillet's chronoscope; Helmholtz's rotating drums; Arago's chronometers (the *chronomètre à pointage*); Perrelet's *chronomètre à détente;* Wheatstone's chronoscope; Schelske's Krille registration apparatus; Hipp's chronoscope; Donders's noematachometer and noematachograph; Marey's drums; Henkel's apparatus; de Jaager and Donders's phonautograph; and the astronomers' artificial transit machines. In the span of a few years, reaction time experiments shifted from being largely criticized by the scientific community to becoming foundational for a new discipline.

Although there were important differences in instrumentation, the overall conception of the experiment remained the same. When a subject reacted to a stimulus, the lag time between stimulus and response was recorded. Scientists separated the duration of thought from the speed of sensory transmission by using "the method of differential nerve lengths" based

22. For a history of the continued association of experimental psychology with reaction time experiments, Germany, and Wundt, see Mitchell G. Ash, "The Self-Presentation of a Discipline: History of Psychology in the United States between Pedagogy and Scholarship," in *Functions and Uses of Disciplinary Histories*, ed. Loren Graham, Wolf Lepenies, and Peter Weingart (Dordrecht: D. Reidel Publishing Co., 1983). For accounts that consider French experimental psychology as limited and flawed compared to German, see Françoise Parot, "La Psychologie scientifique française et ses instruments au début du XXe siècle," in *Studies in the History of Scientific Instruments*, ed. Christine Blondel et al. (London: Rogers Turner Books, 1989); Kurt Danziger, *Constructing the Subject: Historical Origins of Psychological Research*, ed. William R. Woodward and Mitchell G. Ash, Cambridge Studies in the History of Psychology (Cambridge: Cambridge University Press, 1990); John I. Brooks III, "Philosophy and Psychology at the Sorbonne, 1885–1913," *Journal of the History of the Behavioral Sciences* 29 (April 1993). For an account of the continuing failure of experimental psychology in France after the death of Théodule Ribot, see Serge Nicolas and Ludovic Ferrand, "Pierre Janet au Collège de France," *Psychologie et histoire* 1 (2000).

on changing the place in the body to which the stimulus was applied. The speed of nervous transmission was subtracted from the total reaction time to reveal the sought after *speed of thought*.

Mental Origins

The association of these tenth-of-a-second delays with measurements on the speed of thought, however, only appeared later, slowly and polemically. In France, this interpretation first gained currency with a widely reprinted article provocatively titled "La Vitesse de la volonté" (1867), written by the scientist and popular science writer Rodolphe Radau.[23] Astronomers, Radau claimed, had measured the speed of thought: "Thought is not born instantaneously. It is a natural phenomenon subject to the laws of time and space. The lost time is not the same in different observers: one perceives, reflects and moves faster than the other. . . . This explains the differences which have been repeatedly noticed by astronomers who have observed the same phenomenon. Two people have never seen a star pass at the same time behind a vertical wire." Their discovery had, grandiosely, turned the "problem of life" into an "exact science."[24]

Insisting that reaction time experiments measured the time of volition and thought, Radau ignored contrary interpretations favored by other astronomers and physiologists (of which he knew well). He drew heavily on du Bois-Reymond's lectures on "the transmission speed of volition and sensation through the nerves" that were translated in the popular *Revue scientifique.* In them, du Bois-Reymond argued that measurements of "the speed of voluntary and sensory transmission" were a continuation of the work by the eighteenth-century physiologist Albrecht von Haller, who measured the

23. This interpretation contrasted with the one presented in a previous article on the problem of personal errors in astronomy. In it Radau described various interpretations of reaction time. He documented how a number of scientists believed that in well-trained observers the personal equation was a small, immeasurable, relatively uninteresting, and purely physiological phenomenon, equal or analogous to the time of visual persistence. Radau, initially, did not consider reaction time experiments as unambiguously measuring the speed of thought. By his second piece, his initial caution disappeared. His first article was Rodolphe Radau, "Sur les erreurs personnelles," *Le Moniteur scientifique* 7 (1865), and "Sur les erreurs personnelles," *Le Moniteur scientifique* 8 (1866). It appeared in German in Rodolphe Radau, "Ueber die persönlichen Gleichungen bei Beobachtungen derselben Erscheinungen durch verschiedene Beobachter," *Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde, herausgegeben von Dr. Ph. Carl* 1 (1865), and "Ueber die persönliche Gleichungen," *Repertorium für physikalische Technik für mathematische und astronomische Instrumentenkunde, herausgegeben von Dr. Ph. Carl* 2 (1866). These works were cited by Exner and Wundt. Radau used the following sources for his account of Maskelyne: *Zeitschrift für Astronomie, herausgegeben von Lindenau und Bohnenberg* 2 (1816). For Bessel he used C. A. F. Peters, *Ueber die Bestimmung des Längenunterschiedes zwischen Altona und Schwerin, ausgeführt im Jahre 1858 durch galvanische Signale* (Altona: Hammerich & Lesser, 1861).

24. Rodolphe Radau, "La Vitesse de la volonté," *Le Moniteur scientifique* 5 (1868): 91.

time taken by different individuals to read Virgil's *Aeneid* out loud and as fast as possible.[25] In an uncanny coincidence, the speed of nervous transmission found by Haller was approximately the same as the one found almost a century later by du Bois-Reymond's friend and colleague, Helmholtz.[26] Du Bois-Reymond and Radau argued that the decisive step in transforming these experiments into measurements for the speed of thought was currently undertaken by Donders.

Étienne-Jules Marey, the physiologist best known for his use of the graphic method and chronophotography, also adopted this particular interpretation. He became heavily invested in interpreting reaction time experiments as mental, providing an important justification for his earlier frog-muscle investigations. In his opening lecture at the Collège de France for his course on "nervous and mental speed," he framed reaction time as the speed of thought. According to Marey, Donders's recent revelations arose from the comparatively less exciting experiments on frogs he had pioneered. He argued that early experiments on frogs had led to experiments on mental acts. The "knowledge of nervous action which became possible from previous studies on muscular acts," he explained "permitted, in turn, their elevation to the study of mental acts."[27] For years the association of Marey's work on frogs with measurements on the speed of human thought continued largely through his own initiative and that of his supporters. In a tribute to Marey's work, for example, the graphic method was described as central to Donders's work: "Ask M. Donders how the graphic method permitted to separate this physiological time into two parts: the speed of transmission of sensation and volition through the . . . nerves, and the duration of the cerebral work of perception, psychic time."[28] These associations were supported by Marey himself, who among the applications of his graphic method included the "astronomers' personal equation."[29] But at the time of Marey's publication, and for more than a decade already, astronomers were not measuring the personal equation with Marey's methods, but rather

25. The use of the term "reader" to describe the experimenter persisted well into the late nineteenth century.
26. Emil du Bois-Reymond, "Vitesse de la transmission de la volonté et de la sensation à travers les nerfs: Conférence de M. du Bois-Reymond à l'Institution Royale de la Grande-Bretagne," *Revue scientifique* 4, no. 3 (15 December 1866).
27. Etienne-Jules Marey, "Leçon d'ouverture: Vitesse des actes nerveux et cérébraux.—Le Vol dans la série animale, Collège de France, histoire naturelle des corps organisés, cours de M. Marey," *Revue scientifique* 6, no. 4 (26 December 1868): 62.
28. Gavarret, "Observations à l'occassion du procès-verbal. III. Méthode graphique," *Bulletin de l'Académie de médecine* 7 (1878): 760–61.
29. Etienne-Jules Marey, "La Méthode graphique dans les sciences expérimentales," *Travaux du laboratoire de M. Marey* 1 (1876): 145.

with their own artificial transit machines.[30] Furthermore, the interpretation given to the personal equation as mental and its history as originating in 1796 was fiercely debated within various scientific circles. This "standard account" was only one of many others.

Longitude and Astronomy

Essential elements of the "standard account" already appear in some of the earliest descriptions of the discovery of the personal equation. Helmholtz, for example, mentioned the "remarkable fact discovered by Bessel" and frequently referred to the work of astronomers.[31] A few years later the French scientist François Arago, known for introducing the daguerreotype to the general public, gave a much more detailed history of the problem. He explained how Maskelyne, the Astronomer Royal at Greenwich, first noticed individual differences at the end of the eighteenth century.[32] His interest in the problem's history, however, was largely driven by current concerns, where the tenth of a second appeared prominently.

Arago explained how in one particular area of astronomy attention to the tenth of a second was not a "vain luxury," but an urgent need. He referred to the determination of time and longitude where astronomers noted the time in terms of "hours, minutes, seconds, and even tenths of a second." Since "a tenth of a second in time is equivalent to nothing less than a second and a half of arc," ten accumulated mistakes of this magnitude could result in map discrepancies of nearly half a kilometer.[33]

Arago grew increasingly preoccupied with the tenth of a second. In 1853, a few months before his death, he remarked on the need for new chronometers with which he "could read without any doubt tenths of a second."[34] He marveled at a rare instrument now "in my possession, made in Vienna" in which the hand, instead of making a complete turn in a minute, "made a complete turn in a second." He also called attention to new American-built

30. Marey went to the Observatoire de Paris to learn about Wolf's machine for measuring the personal equation. Marey, *La Méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine*, 148. Marey also cited the work of the astronomers Prazmowski, Hänckel, Hirsch, and Plantamour.
31. Helmholtz, "Ueber die Methoden, kleinste Zeittheile zu messen, und ihre Anwendung für physiologische Zwecke," 325, and "On the Methods of Measuring Very Small Portions of Time, and Their Application to Physiological Purposes," 189.
32. François Arago, "Note sur un moyen très-simple de s'affranchir des erreurs personnelles dans les observations des passages au méridien," *Comptes rendus des séances de l'Académie des sciences* 36 (1853).
33. These errors were larger the closer observations were to the equator. Ibid.
34. Ibid.

electric clocks that could be adapted for measuring these short periods of time.[35]

Arago's interest in the exact determination of longitude was not only due to its importance for mapmaking and navigation. It was also relevant for the precise determination of the length of the meter. He claimed that "many years ago" errors of this magnitude had been used by a member of the Académie as an explanation of the "extraordinary and difficult to explain anomaly" that haunted the famous meter bar of 1799.[36] That meter bar had been defined as a 1/10,000,000th part of the earth's quadrant circumference, and errors in its determination spread to those of the meter based on it.[37]

Joseph Delambre and Pierre Méchain were in charge of a vast project to determine the length of the meter. Their main task was to provide the geodesic measurements for this project, which led them to embark on a seven-year-long odyssey considered to be the most important scientific mission of the era. Yet when Napoleon unveiled a new platinum meter bar based on their results, this standard faced a difficult future. Although astronomers who participated in the project presented an optimistic picture to the public, they knew it housed a dangerous error.

Tenth-of-a-second errors in determinations of the earth's circumference appeared at the center of a crisis—a crisis striking at the essence of measurement. These same errors haunted Arago's other projects. They were the "only key" that he believed might account for the "paradoxical and constant variations" found by Alexander von Humboldt and himself when they determined the latitude of Paris in 1809. Nearing the end of his life, Arago dusted off various essays published as early as 1816 and proudly proclaimed that he had studied personal equation errors many years before a furor of interest started surrounding them.[38] He reminded his colleagues of an 1842 publication where he had brought to the attention of the Académie "a cause of error which up to now had never appeared in an analogous work" affect-

35. Ibid.

36. François Arago, "Rapport sur deux mémoires présentés, l'un par M. Eugène Bouvard, l'autre par M. Victor Mauvais, relatifs à l'obliquité de l'écliptique," *Comptes rendus des séances de l'Académie des sciences* 15 (1842): 946, and "Mémoire sur les cercles répétiteurs," in *Oeuvres de François Arago* (Paris: Théodore Morgand, 1865), 121.

37. For the history of the expedition to find the length of the meter see Ken Alder, *The Measure of All Things: The Seven-Year Odyssey and Hidden Error That Transformed the World* (New York: Free Press, 2002). Alder mentions the relation to the personal equation on p. 307.

38. This work was first published in 1816 in the *Connaissance des temps* for 1813. Arago remarked on errors that only surfaced when different observers were involved. Tests on the accuracy of instruments, he suggested, should always be done "under the same circumstances, and especially by the same person." Arago explained how the source of these errors might lay in a "visual defect" of the observer. He called them "erreurs constantes de pointé." Arago, "Mémoire sur les cercles répétiteurs," 128.

ing two of his junior astronomers.[39] He referred to the contested concept of a "personal," "distinct," and "individual collimation" that "varies from one observer to the other, and for the same observer, according to the eye used."[40] In his early work Arago had insisted that these "distressing and so singular anomalies" were most probably due to optical and physical causes, but the problem of individual biases soon became more complicated.[41] He and others started to look beyond optics.

Personal equation errors plagued the traditional skill-intensive "eye-and-ear method" for determining longitude, which was difficult, requiring the full attention of highly trained and talented astronomers. This method consisted in estimating the position of a star across the reticules of a telescope between successive one-second-long clock beats. Talented observers could determine the star's position at tenth-of-a-second intervals, but errors were frequently larger. Arago argued that if astronomers used chronometers to note the time of a star's passage (instead of estimating this moment between one-second clock beats), these errors might be significantly reduced.[42]

Starting in the 1860s astronomers increasingly used telegraphic methods (sometimes referred to as the "American method" or "electro-chronography") for time and longitude determinations.[43] These technologies permitted them to determine time by pressing a key when a transit star passed through the reticules of their telescopes and recording the moment on a moving strip of paper. With these instruments, they replaced the "eye-and-ear method." Yet even with telegraphy and automatic inscription devices, the best observers were rarely able to avoid errors of the order of a tenth of a second. While working with these electric technologies, scientists became

39. François Arago, "Rapport sur deux mémoires présentés, l'un par M. Eugène Bouvard, l'autre par M. Victor Mauvais, relatifs à l'obliquité de l'écliptique," 945–46.

40. Ibid., 945.

41. Arago warned how they could change according to the position of the body of the observer vis-à-vis the stars and also with respect to the eye used. Ibid., 946.

42. Arago believed that tenth-of-a-second errors arose in connection to mental work, and he prompted astronomers all over the world to adapt their observational methods to reduce mental fatigue. Astronomers became part of the larger effort to mechanize work and mental processes, concerning industrialists, accountants, and mathematicians like Charles Babbage, the creator of some early calculating machines. In his personal notebook, Babbage explained how fatigue affected his own personal equation. "There was however not merely a personal equation but a *periodic* personal equation. For I found on trial that my own accuracy . . . varied with the state of bodily fatigue." Charles Babbage, Papers on Astronomy, 1862, British Museum Library Manuscript Collection (emphasis in original). These observations were alluded to much earlier, but without attributing them to the "personal equation," in Charles Babbage, *Reflections on the Decline of Science in England, and Some of its Causes* (New York: A. M. Kelley, 1830; reprint 1970), 173–74.

43. The Bonds at Harvard and Adolph Hirsch of Neuchâtel were some of the first to use these technologies. The Bonds used an electric clock, similar to the one used by Alexander Dallas Bache for the trigonometric drawing-up of the U.S. coastline.

increasingly concerned with the time that elapsed between stimulus and response. They inquired into the speed of electric transmission, the inertia of inscription devices, and lag times due to observers.[44]

Shortly before his death, nearly blind, and a disillusioned witness to yet another hijacked republic, Arago portrayed the most important years of his career in a manner that was dramatically different from that which he had previously revealed. He talked about observation errors in public and loudly, freely reminiscing about the role of "observational errors" in his decades-old investigations.[45] Arago remembered how at the time, a number of his colleagues did not accept his theory. Most prominently among them was the German mathematician Friedrich Gauss, who was responsible for developing an alternative theory of errors and who examined Arago's work "with some severity in the Gazette littéraire of Leipzig."[46]

Gauss developed a mathematical technique for eliminating errors, frequently called the "least squares" method, which consisted in giving observations lesser weight depending on the square of their deviation from the mean. His work enabled investigators to sort errors that would eventually be called "random" or "accidental" from those called "constant" or "systematic." The pattern of the former would follow the famous bell-shaped curve, which was also called "Gaussian."

In contrast to Gauss, Arago considered observation errors of an entirely different nature. These persisted even when observations were repeated and averaged and even when subjected to the least squares method. They did not display the same bell-curve shape as random errors, and they did not disappear by using traditional instruments (such as microscopes and telescopes) previously legitimated as expanding the reach of the senses. These errors could no longer be explained away by invoking the well-known universal fallibility of the senses or by using these new mathematical techniques.

In the Paris Observatory, research on individual differences in observation started in the 1840s under Arago and increased dramatically in the

44. Another complication involved understanding how the speed of nerve transmission was affected inertially. How were reactions to stimuli affected by the movement of the observer, for example, when traveling on a train? Scientists needed to account for acceleration effects on the nervous system: "Now suppose that the mechanic on a locomotive of an express train traveling one mile (English) per minute extends his arm towards the tender and moves the fingers, then the movement of the nervous agent is destroyed by the movement of the train." This situation was "the same as when the movement of a cannon ball thrown towards the equator from the west is destroyed by the movement of the earth around its axis. In that case it is not the cannonball that hits the boat, but rather the boat that hits the cannonball." Bois-Reymond, "Vitesse de la transmission de la volonté et de la sensation à travers les nerfs: Conférence de M. du Bois-Reymond à l'Institution royale de la Grande-Bretagne," 39.

45. François Arago, "Sur les observations des longitudes et des latitudes géodésiques," in *Oeuvres de François Arago* (Paris: Théodore Morgand, 1865), 147.

46. Arago, "Mémoire sur les cercles répétiteurs," 120.

Corrections personnelles à appliquer aux heures de passage observées de 1837 à 1853.

	RD.	L.	P.	VM.	O.	F.	YV.	B.	CH.	EL.
1837.	0s,00	−0s,01	+0s,44	0s,00						
1838.	0,00	−0,04		0,00						
1839.	+0,02	−0,07		0,00						
1840.	+0,04	−0,10		0,00						
1841.	+0,05	−0,13		0,00	−0s,19					
1842.	+0,05	−0,13		0,00	−0,38					
1843.	+0,05	−0,13		0,00	−0,50	+0s,01				
1844.	+0,06	−0,13		+0,01	−0,53	+0,05				
1845.	+0,06	−0,13		+0,02	−0,57	+0,09	0s,00	−0s,12		
1846.	+0,06	−0,13		+0,03	−0,61	+0,14	0,00	−0,12		
1847.		−0,13		+0,04	−0,65	+0,19	0,00	−0,12		
1848.		−0,14		+0,04	−0,61	+0,15	−0,02	−0,09		
1849.		−0,14		+0,05	−0,59	+0,12	−0,02	−0,08		
1850.		−0,14		+0,07	−0,58	+0,10	−0,02	−0,07		
1851.		−0,13		+0,09	−0,56	+0,07	−0,03	−0,06	−0s,35	
1852.		−0,13		+0,12	−0,54		−0,03	−0,06	−0,40	−0s,14
1853.		−0,15		+0,16	−0,52		−0,04	−0,06	−0,43	+0,04

Figure 2.2. Personal corrections for observers published under the directorship of Le Verrier applied to observations from 1837 to 1853. The initials above each column designate the observers. From "Réduction des observations faites aux instruments méridiens," *Annales de l'Observatoire impérial de Paris, Observations* 2 (1859), p. xli.

decades after his death during the Second Empire. When the astronomer Urbain Le Verrier succeeded Arago as director of the Paris Observatory, the problem was so pervasive that he decided to apply personal corrections retrospectively: to the observations done under Arago from 1837 to 1853. Every observation was shifted in time by a few tenths of a second, forward or backward, depending on the observer. In the 1850s observers at most major astronomical observatories started to be tested for their personal equations. By the end of Napoleon III's reign in the 1870s, all the observers in the Paris Observatory were tested.[47]

The astronomer Hervé Faye was particularly pessimistic about the extent of these errors. All "determinations of absolute time" used in astronomy, Faye noted, were implicated: "One knows, since the beginning of this century, that this determination [of time] is completely illusory." According to him, only "relative time" could be found, and this one, ironically, with a much greater precision. Methods for determining time and longitude—including telegraphic ones—had to contend with the problem that "sensations separated by a very real interval will be falsely noted as simultaneous."[48]

47. François Gonnessiat, *Recherches sur l'équation personnelle dans les observations astronomiques de passage*, Annales de l'université de Lyon (Paris: G. Masson, 1892), 3:159.

48. Hervé Faye, "Sur les erreurs d'origine physiologique," *Comptes rendus des séances de l'Académie des sciences* 59 (12 September 1864): 475.

The problem plagued not only France and its observatories, but "all places where one observes, with an admirable precision, astronomical phenomena." The scourge reached as far as Poulkova, Koenigsberg, and Greenwich, sites of the most important observatories and, places where "one could not find two observers who would reach accord on absolute time."[49]

Because of the problems he noticed in astronomical practices, Faye was led to the conclusion that the human "spirit" was not infinitely fast:

> Imagine that the spirit is an eye in the center of the brain; an eye attentive to the changes that each sensation causes in the nerve cells that lead to it. If similar sensations occur at the same place, this internal eye will easily tell whether they occurred at the same time or one after another. But if these sensations come from different senses where the nerves end up at different parts of the brain, the internal eye will need to move in order to go from one area to another, and the time spent doing this will not be detected. Sensations separated by a very real interval will be wrongly perceived as having occurred at the same time. The lost time used to go from one sensation to the other can amount to over a second. It will in fact vary from one individual to another, depending on the speed at which the internal eye moves to successively study the keys of this prodigiously complex keyboard [clavier] that is called the brain.[50]

The famous physicist Henri Victor Regnault (whom Helmholtz described as the best French scientist) explained how determining these errors was urgent. The "non-instantaneity of transmission, not only in personal organic sensations, but also in the telegraphic registering apparatus" was a matter about which "one must worry enormously." Yes, it was important to determine the time of transmission in the wires of the equipment and the inertia

49. Hervé Faye, "Sur les observations du soleil," *Comptes rendus des séances de l'Académie des sciences* 28 (1849): 243.

50. Individual differences in observation, according to Faye, were caused by the different speeds of the "internal eye." For Faye a "lost time" arose when different impressions were compared to each other. This delay was mostly due to the mind, since Faye surmised that nerve transmissions "probably" occurred at a "rapidité toute électrique" and "should be almost the same for all individuals." This mental work was fatiguing: "The fact remains that the need to compare two sensations coming from different origins forces the spirit [*esprit*] to a very peculiar task, as it spends such a considerable amount of time establishing communication between different nerve cells. Moreover this task is very tiring, while the comparison of sensations from the same origin is not, or much less so." Faye, "Sur les erreurs d'origine physiologique," 475–76. Cited in Gonnessiat, *Recherches sur l'équation personnelle dans les observations astronomiques de passage*, 120, and translated in Sanford, "Personal Equation," 413 n. 1. Even the auditory method of coincidences long used for comparing and synchronizing clock signals was affected by these personal errors. Although the trained ear registered coincidences in rhythmic sounds to an uncanny degree, this method was not free from them. Faye impressed Airy in 1854 by noticing a difference between two pendulums separated by four meters using the method of coincidences. Hervé Faye, "Sur la méthode des coïncidences appliquée à la mesure de la vitesse du son et sur la détermination des longitudes," *Comptes rendus des séances de l'Académie des sciences* 55 (1862).

of the registering apparatus, but Regnault insisted especially on "the errors due to the personal appreciation of the observer," which were "significantly larger."[51] Scientists like Regnault noticed that too many experiments and measurements were predicated on an architecture of the body that ignored the time of internal transmissions and individual differences. New investigations on personal errors questioned the legitimacy of these experimental systems. If time and length were not absolute, what was?

Measurements of Lengths

Another important aspect of the personal equation that was obscured in standard accounts pertained to other, even simpler, measurements, such as length. Cutting across the life and physical sciences, personal equation errors affected disciplines far from astronomy—everywhere exact measurements were used. The history behind these efforts can help us understand how measurement gained the privileged position it would hold for the next century. It can help us voice the complex negotiations behind the establishment of measurement-based science.

In most accounts, measurement appears as a simple, straightforward activity. Inasmuch as it is simple, it is not worthy of examination. Yet numerous difficulties lay behind the establishment of measurement-based science. These measurement problems were interdisciplinary. Challenges faced by astronomers and physicists were the same as those affecting anthropometric measurements used to identify individuals for policing and colonial purposes.[52]

Scientists noticed that in the process of measuring the size of rulers, different individuals assigned slightly different lengths to these standards. These errors, referred to as "individual collimations" or "erreurs de pointé," appeared when leveling an instrument or, when using a micrometer, when bringing two marks in line with each other. They also surfaced when observers tried to find the exact center of circles and dots and the precise alignment between distinct objects—whenever scientists set the crosswires of an instrument on the division mark of a scale. Personal equations soon appeared even in such apparently simple activities as measuring the diameter

51. These "were always significantly larger than those which come from telegraphic register systems." Regnault, "Remarque de M. Regnault à l'occasion de la note de M. Faye," *Comptes rendus des séances de l'Académie des sciences* 59 (1864): 479–80.

52. The criminologist Alexandre Lacassagne remarked on the "serious obstacle of the personal equation." Alexandre Lacassagne, *Alphonse Bertillon: l'homme, le savant, la pensée philosophique* (Lyon: A. Rey, 1914), 16.

of the sun and moon.[53] Metrologists concerned with determining standards of length were forced to measure the personal equation of their observers. At times, they even asked observers to sign their observations. These errors constituted a particular danger since they affected both spatial and temporal measurements. They spread to affect perceptions of brightness, taste, temperature, and weight.

Scientists traced the spread of personal equation problems to measurements of length to the comparison of English yards undertaken by the English astronomer Francis Baily in 1835.[54] That year Baily undertook a detailed project to measure and determine the length of different standards. In the process, he noticed a problem that arose when he tried to bisect the dots of a ruler with the cross wires of his measuring instrument. Because these dots resembled stars, he explained, his measurements of length were affected by the astronomical problem of the personal equation. Baily's work was alarming since it showed that the problem noticed by astronomers when reacting to a transit star crossing the wires of a sighting device was also present in passive, leisurely observations: "I believe that it seldom happens that two persons, chosen indifferently, will agree precisely in their measures of a line, or a dot with the cross wire of the micrometer; but that there will almost always be some slight difference between their results: similar to what takes place in observations with transit instruments, where this anomaly is styled the *personal equation,* a term which I shall employ on the present occasion."[55]

Baily vacillated between thinking that individual differences were due "to a peculiar state of vision, or to a peculiar mode of making the bisections,"

53. A personal equation in the observation of the borders of the sun and moon was frequently noted. In the Paris Observatory investigations on these differences were carried out in 1856 and published in the *Annales de l'Observatoire de Paris, observations* 12 (1860): 131. They were described in Gonnessiat, *Recherches sur l'équation personnelle dans les observations astronomiques de passage,* 88. Le Verrier remarked on the individual differences in estimating the diameter of the sun in 1858. He attributed these errors to "systematic differences in the manner of observing." Urbain Le Verrier, "Théorie et tables du mouvement apparent du soleil," *Annales de l'Observatoire impérial de Paris* 4 (1858). Encke's number for the sun's diameter (31′56.84″, deduced from the eighteenth-century transits of Venus) differed from many others, especially from the one Le Verrier had found by observing transits of Mercury (32′0.02″). Both of these values differed markedly from the ones obtained from direct measurements during an 1842 total eclipse.

54. Arago disagreed with the attribution of the "origin" of the discovery of personal errors in measurements of length to Baily. He called it a *petite malice* from Faye. Arago insisted it was him, and not the British astronomer, who was the discoverer. "The *petite malice* that the author [Faye] permitted himself could have been very tasteful if the year 1816, date of the publication in the *Connaissance du temps* of a frequently cited Mémoire, had not preceded the year 1834 or 1835." Arago, "Sur les observations des longitudes et des latitudes géodésiques," 147. This work summarized numerous discussions that took place at the Académie des sciences during the early part of 1853.

55. Francis Baily, "Report on the New Standard Scale of this Society. Drawn Up at the Request of the Council, by F. Baily, Esq. F. R. S. and C., and One of the Vice-Presidents of the Society. Presented December 11, 1835," *Memoirs of the Royal Astronomical Society* 9 (1836): 92. Italics mine.

1834.	Nº of Obs.	Scales.	Person. Equat.	Mean.	Observers.
			div.	div.	
April 5	10	Ast. Soc.	0·19	0·19	Murphy and Baily.
April 2	10	Shuckburgh	6·64	6·64	Murphy and Donkin.
April 3	10	Russian	7·19	7·04	Murphy and Donkin jun.
April 4	10	Ast. Soc.	6·89		
March 22	5	Ast. Soc.	4·80	4·72	Murphy and Henderson.
March 24	20	Danish	5·70		
April 3	10	Shuckburgh	5·76		
April 4	10	Russian	1·47		
April 5	10	Ast. Soc.	4·96		
March 24	8	Danish	3·27	4·08	Murphy and Johnson.
March 25	10		4·89		
March 24	10	Danish	4·40	4·40	Baily and Donkin.
April 4	10	Ast. Soc.	3·08	3·08	Baily and Henderson.
April 3	10	Russian	4·30	3·07	Henderson and Donkin jun.
April 5	10	Ast. Soc.	1·84		
April 3	10	Shuckburgh	1·36	1·36	Johnson and Henderson.

Figure 2.3. Table comparing the length of different standards of measurement. The middle column shows the observers' personal equation when measuring different scales of length. From Francis Baily, "Report on the new Standard Scale of this Society. Drawn up at the request of the Council, by F. Baily, Esq. F. R. S. and C., and one of the Vice-Presidents of the Society. Presented December 11, 1835," *Memoirs of the Royal Astronomical Society* 9 (1836): 35–184, on p. 110.

but something was clear: "Each individual has some real or imaginary cause of preference for selecting the precise portion of the line or dot under consideration, which may differ from that other person."[56] Part of the problem arose because rulers' dots were frequently "not circular, but of an irregular pear-shaped form." Baily suggested using the short, straight lines used today instead of dividing the standard with "enormous and irregular" dots.[57] He contended with fatigue, increased the number of observations, measured the personal equation of different observers, and had them exchange places from one side of the ruler to the other. He fought against the "distracted attention of the observer" by employing an amanuensis.[58]

His investigations showed inherent difficulties in measuring, and even worse, in making "true copies." Even the simplest measuring tasks required

56. Ibid., 96.

57. Ibid., 92. Baily contrasted these dots to the "fine" and "scarcely perceptible" lines of the French meter.

58. Ibid.

complicated and highly disciplined bodily skills.[59] The standard should remain "untouched by the hands of any clumsy or inexperienced workman, or experimentalist"[60] and only be handled by those "conversant with micrometrical measurements."[61] Anything that touched a ruler would alter its pristine length. Focus now switched to the ruler's bedding and to things affecting the bedding—not only temperature but also the floors and walls of the laboratory. These concerns led him to an infinite regress that spread from the inside of the observer to the world outside of the laboratory. But the problem did not end there. In despair, he recommended that all measurements involving rulers, even those undertaken with a micrometer, be signed.

The endeavor, at times, seemed self-defeating. How could scientists escape the vicious circle in which both observations and reactions were affected? Astronomers altered their methods and instruments often following solutions volunteered years earlier by Baily. They isolated their workplaces. When measuring longitudes they exchanged places (say London and Paris) in the same way Baily switched observers from one end to another end of a ruler. They tried minimizing fatigue by increasing the division of labor in the observatory. They cared about the attention of observers, making sure their laboratories and observatories were silent and free from distractions.[62] Distorted, seemingly asymmetrical stars and planets were treated much like the pear-shaped dots that often divided rulers, and, using prisms, were corrected.

Baily's instructions were carefully followed by later generations. More than half a century after they were published, a prominent metrologist could still claim that Baily "gave instructions that, on many points, can serve as a guide to the metrologists of today."[63] Yet the problem did not disappear.

Beyond Astronomy and Experimental Psychology

Scientists, philosophers, and writers across disciplines and nations used the terms "reaction time" and "personal equation" outside of the institutional

59. Ibid., 36, 39n. For the role of bodily skills in the production of knowledge, see H. Otto Sibum, "Les gestes de la mesure: Joule, les pratiques de la brasserie et la science," *Annales HSS* 4–5 (1998).
60. Baily, "Report on the New Standard Scale of this Society. Drawn Up at the Request of the Council, by F. Baily, Esq. F. R. S. and C., and One of the Vice-Presidents of the Society. Presented December 11, 1835," 93n.
61. Ibid., 96.
62. For experiments on the disruption brought about by the regular noises of the chronograph, see Gonnessiat, *Recherches sur l'équation personnelle dans les observations astronomiques de passage,* 118.
63. J.-René Benoît, "De la précision dans la détermination des longueurs en métrologie," in *Rapports présentés au congrès international de physique réuni à Paris en 1900,* ed. Ch.-Éd. Guillaume and L. Poincaré (Paris: Gauthier-Villars, 1900), 61, 62.

confines of experimental psychology and astronomy. A famous American psychologist described the personal equation as having "interesting ramifications into physiology, psychology and anthropology."[64] Repercussions were felt elsewhere as well, in art.

The term "personal equation" slowly gained currency in the broader culture. Its meaning expanded to include a broader set of personal differences that went far beyond the differences noticed by astronomers in the timing of star transits. Through the course of the century it became a term used to describe personal opinion and bias. The following definition from Webster's dictionary reveals the complex meaning of the term, ranging from astronomy to everyday judgments:

> Personal equation: The difference between an observed result and the true qualities or peculiarities in the observer; particularly the difference, in an average of a large number of observations, between the instant when an observer notes a phenomenon, as the transit of a star, and the assumed instant of its actual occurrence; or, relatively, the difference between these instants as noted by two observers. It is usually only a fraction of a second;—sometimes applied loosely to differences of judgment or method occasioned by temperamental qualities of individuals.

In a book titled *The Personal Equation* (1925), Louis Berman, a famous endocrinologist who explained how hormones affected personality, also remarked on the changing meaning of the term: "'The personal equation' is a phrase that was first invented in the eighteenth century in relation to errors in astronomical observations. . . . By transfer of the general meaning of the term the phrase came to be applied to all those individual peculiarities and idiosyncrasies which have to be taken into account in estimating personality."[65] In the 1920s, an important scholar of American literature maintained that "criticism is the science of the personal equation."[66] During this period, a whole biographical genre, titled the personal equation, was born.[67]

64. In 1888 Edmund C. Sanford, a psychologist and editor of the *American Journal of Psychology,* scrutinized the work of astronomers in a widely read history of the personal equation that inspired a generation of American experimental psychologists. Sanford, "Personal Equation," 25. He considered it "important alike to astronomy and anthropology." Ibid., 9.
65. Louis Berman, *The Personal Equation* (New York: Century Co., 1925), 299–300.
66. Percy H. Boynton, *Some Contemporary Americans: The Personal Equation in Literature* (Chicago: University of Chicago Press, 1924).
67. Harry Thurston Peck, *The Personal Equation* (New York: Harpers, 1897); Lawrence McTurnan, *The Personal Equation* (New York: Atkinson, Mentzer & Grover, 1910); Albert Guérard, *Personal Equation* (New York: W. W. Norton and Co., 1948). The Nobel Prize winner Eugene O'Neill used the term as the title for an unpublished play (1915).

From the late nineteenth to the early twentieth century, a number of thinkers and writers used the term in a broader sense. The famous sociologist Thorstein Veblen denounced the corporatization of American universities by lamenting their rejection of the valuable element of "personal equation" (1918).[68] The New England painter Charles H. Woodbury explained how it signified "individual opinion, a preference without the possibility of proof" (1919).[69] William James, professor of philosophy at Harvard University, described the "original 'personal equation' observation of [the German astronomer] Bessel," but also employed the term in its other sense.[70] When commenting on "the methods and snares of psychology," he warned how the study "of animals, savages and infants is necessarily wild work, in which the *personal equation* of the investigator has things very much its own way."[71] While the term "personal equation" was increasingly used as a label for personal opinion in literary contexts, this meaning also appeared in scientific publications.

Opinion and Testimony

The famous mathematician Karl Pearson, Francis Galton's most loyal follower, connected the personal equation to the differences in the testimony given by different individuals in general observations. Although in his work on the personal equation he mostly focused on "observations such as are daily made in the physical laboratory or the observatory"[72] and those "typical of the measurements usually made by physicists and astronomers,"[73] his conclusion informed "all types of observation." After reviewing the work of French and British astronomers, he concluded that "there is a real individuality in observation which manifests itself in the personal equation."[74] Observational errors were not entirely random, as previous researchers had often assumed, but they depended on "mental or physical likeness" and "common elements in personalities" of the observers. Neither averaging results or applying the "least squares" method solved the problem.

Pearson's investigations on the personal equation led him to rework traditional concepts of truth and testimony. In the eighteenth century, Hume argued that the testimony of individuals could never outweigh the empirical testimony of the uniform laws of nature. Hume's insight was subsequently developed into a probability theory of testimony, where accounts given by independent witnesses were considered to be mathematically independent. More than two centuries later, Pearson noticed that the testimony of different individuals could be interrelated and correlated in complex ways. His conclusions "appear to vitiate very largely the existing theory of the probability of testimony."[75]

In contrast to Hume's classic theory of testimony, Pearson took into account bodily—not only moral—differences and similarities between witnesses. His conclusion was radical: testimony was affected by biometrical "correlations" that appeared even if observers witnessed "independently." In the course of his experiments, he found that individual differences in measurements were sometimes correlated to genetic differences. Personal equation correlations could be "as high as that of a measure made on a pair of brothers."[76] After his work on the personal equation, correlation techniques, where the value of observations made by independent observers was given a probabilistic weight depending on how they related to each other, flourished.

68. "Whereas it may be fairly said that the personal equation once—in the days of scholastic learning—was the central and decisive factor in the systematization of knowledge, it is equally fair to say that in later time no effort is spared to eliminate all bias of personality from the technique or the results of science or scholarship." Thorstein Veblen, *Higher Learning in America* (New Brunswick, N.J.: Transaction, 1993 [1918]), 5.

69. Charles H. Woodbury, *Painting and the Personal Equation* (Boston: Riverside Press, 1919), 57.

70. William James, *Principles of Psychology* (New York: Dover Publications, 1950), 1:413. For the broader sense in which William James referred to the personal equation, see also his "Report on Mrs. Piper's Hodgson-Control," *Proceedings of the American Society for Psychical Research* 23 (1909): 2–21, reprinted in *William James on Psychical Research*, ed. Gardner Murphy and Robert O. Ballou (Clifton, N.J.: Augustus M. Kelley, 1973).

71. James, *Principles of Psychology*, 1:194. Cited in Sonu Shamdasani, *Jung and the Making of Modern Psychology: The Dream of a Science* (Cambridge: Cambridge University Press, 2003), 34. Italics mine.

72. Karl Pearson, "On the Mathematical Theory of Errors of Judgment with Special Reference to the Personal Equation," in *Early Statistical Papers* (Cambridge: Cambridge University Press, 1948), 432. Originally published as Karl Pearson, "On the Mathematical Theory of Errors of Judgment with Special Reference to the Personal Equation," *Philosophical Transactions of the Royal Society of London* 198 (1902).

73. Pearson, "On the Mathematical Theory of Errors of Judgment with Special Reference to the Personal Equation," 379. Pearson discovered that the typical manner of calculating probable errors, consisting in using the "least squares" technique developed earlier in the century, was insufficient. In order to apply the least squares method to measurements, errors had to be random and should follow the famous bell-shaped curve. Yet Pearson's showed that "personal equation" errors were not random and that they did not follow the normal distribution curve. Ibid., 400. "The distribution of errors of judgment can diverge in a very sensible way, both on account of asymmetry and of flat-toppedness, from the Gaussian curve of errors." Ibid., 424. In the 1890s Pearson designed a special machine to measure the personal equation of observers, and he submitted himself to it for nearly five years. The machine reflected a moving bright line of light unto a sheet of paper. The person doing the experiment was asked to mark the line's position at the ringing of a bell. The position of the line as determined by the machine and its *perceived* place were then compared to each other in order to deduce the observer's personal equation. Pearson became particularly interested in comparing the personal equation of different observers and correcting for any unforeseen correlations among them. Referring to Dr. Lee and Dr. Macdonell, two colleagues who joined him in his personal equation experiments along with Horace Darwin, Charles Darwin's son, he explained: "If Dr. Lee and Dr. Macdonell assert that a bright light was in certain position when the bell rang, their united testimony is very far from having the weight it would have on the old mathematical theory that they are independent witnesses, and yet they record perfectly 'independently.'"

74. Ibid., 433n.

75. Ibid., 433.

76. Ibid., 404.

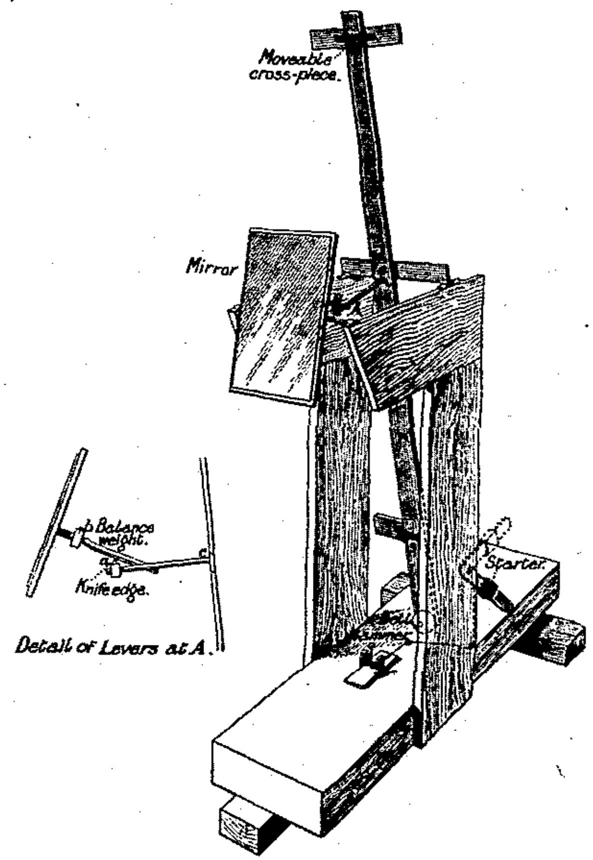

Fig. 1.—Apparatus for Personal Equation.

Figure 2.4. Personal equation machine used by Pearson. From Karl Pearson, "On the Mathematical Theory of Errors of Judgment with Special Reference to the Personal Equation," in *Early Statistical Papers*, 377–441 (Cambridge: Cambridge University Press, 1948; originally published 1902), p. 391.

Biography and the Unconscious

Personal equation and reaction time research flourished in light of its connection to other measurable elements such as race, sex, age, intelligence, and state of health. While experimental psychologists increasingly focused on reaction time measurements, other scientists found its significance to be even broader: reaction time measurements could potentially give valuable information about a person's personality and biography; they could be revealing of a person's deepest secrets or unconscious thoughts.

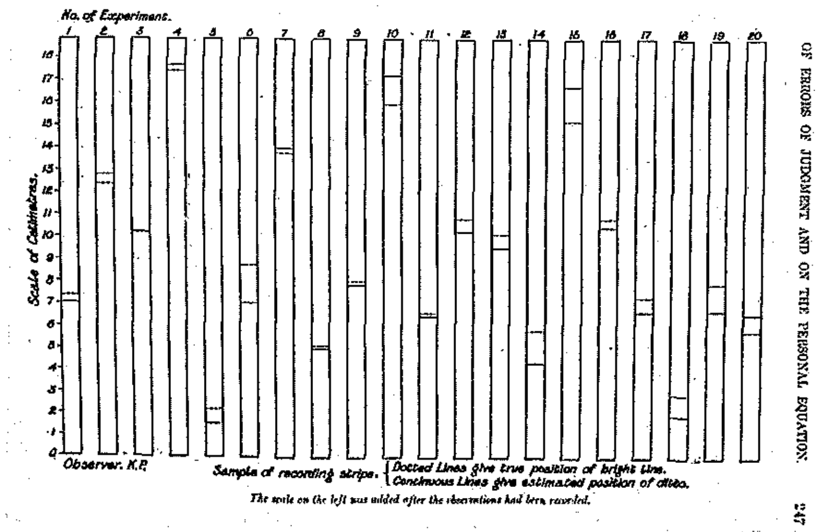

Figure 2.5. Results from Pearson's experiments showing slight disagreements between the position of a bright light, and the observer's estimation of the position. From Pearson, Karl. "On the Mathematical Theory of Errors of Judgment with Special Reference to the Personal Equation." In *Early Statistical Papers*, 377–441 (Cambridge: Cambridge University Press, 1948; originally published 1902), p. 389.

Wilhelm Ostwald, who won the Nobel Prize in Chemistry in 1909, resisted the increasing specialization of reaction time research taking place at the turn of the century in dedicated laboratories and turned to reaction time as a method for applying a "scientific point of view" to social and political problems. Many researchers, including the famous sociologist Max Weber, criticized Ostwald's "Umstulpung," or spillover, of the scientific worldview into the social sciences. Yet numerous others scientists were inspired by his attempt to broaden the reach of science beyond its clinical and laboratory moorings.

In *Grosse Männer*, published the same year he was awarded the prestigious Nobel Prize, Ostwald studied the personalities of great men, all scientists, in terms of their speed of reaction. He argued that scientific personalities could be divided into two broad categories, romantics and classics: "The speed of mental reaction is a decisive criterion for determining to which type a scientist belongs. Discoverers with rapid reactivity are romantics, those with slower reactions are classics." Reaction time, most importantly, did not have to be measured chronographically, but could be deduced from everyday engagements, such as from the time taken to respond to a student's question.[77] Ostwald reminded his readers how Helmholtz "never reacted on the instant, but only after a long time."[78] The controversial chemist did not see a particular benefit from having reaction time be short or long. Both had distinct advantages. What was important for him was how they were used to harness energy and prevent dissipation. Ostwald's biographical reaction time studies formed part of his theory of energism, an antimaterialist doctrine that stressed continuous change over physical permanence. Energy was the primary substance in the world and matter was only derivative of it.

Sigmund Freud was so intrigued by Ostwald's theory that he conceived his theory of instinct and drives in terms of similar energy flows.[79] In his famous *Psychopathology of Everyday Life,* Freud praised the reaction time studies of his favorite student Carl G. Jung, who found that reaction time tests could be used as lie detectors.[80] His method consisted in having a subject respond to a word stimulus with another word and measuring the time taken to produce a word association. Although the actual word associations became increasingly important for him, initially he was only concerned with the time of reaction. Jung noticed that "women reacted considerably more slowly" and that "uneducated subjects . . . produce much higher figures than educated ones." These initial results soon became more complicated. He investigated how reaction time varied according to the kind of word stimulus that was used: whether it was a verb, a noun, or an adjective, or whether it was abstract or concrete. He then delved even deeper by focusing on individuals, their biographies, and how these were related to their particular word associations. On one occasion a subject took an unusually long time to react to the word stimuli of "lake" and "to swim." This had an explanation: "If we ask the subject now why he hesitates at these points, we learn that once in a moment of despair he had seriously contemplated suicide by drowning." Finding that this hesitation "is quite involuntary and

77. "In what concerns applied psychology, one knows that there is a deep abyss between experimental psychology and the practical art of understanding men and managing them correctly. The results of the first, that seem easy to grasp, have accumulated an enormous mass of facts of observation and speeds of reaction, etc.; but all that . . . does not have any utility, if the goal is to understand and judge men in a general way." Wilhelm Ostwald, *Les Grands Hommes,* trans. Marcel Dufour, Bibliothèque de philosophie scientifique (Paris: Ernest Flammarion, 1912), 197.
78. Ibid.
79. The indispensability of energism was most clearly stated in his "Unconscious" (1915) publication. For energism in Freud and Lacan, see Richard Boothby, *Freud as Philosopher: Metapsychology after Lacan* (New York: Routledge, 2001).
80. Sigmund Freud, *Psychopathology of Everyday Life* (London: T. Fisher Unwin, 1914 [1901]), chap. 12, n. 8. Carl G. Jung, ed., *Diagnostische Assoziationsstudien: Beiträge zur experimentellen Psychopathologie* (Leipzig: Barth, 1906).

a kind of reflex," Jung turned to cases where he did not have "co-operation from the subject" and used this method to discover a crime.[81]

When an elderly gentleman went to Jung suspecting that his protégé, a young man of eighteen, had stolen from him, the psychologist decided to try his association experiments on the young man and quickly noticed that words such as "police," "arrest," and "jail" elicited unusually long reaction times. Finding that "the total result of this experiment appeared so convincing," he accused the man of stealing. In light of this accusation, the unveiled criminal turned "suddenly pale." After some protesting, he "burst into tears and confessed."[82]

Race

While certain writers considered the personal equation as a marker of opinion, as prejudice, and as an element affecting observations, others took it to be a privileged window into a person's mind and body. The personal equation could be a way to connect visible elements in a person (such as race) with invisible ones, such as the mind.[83] The famous British scientist Francis Galton found in the personal equation the much sought-after link between physical and mental qualities. Convinced that "the magnitude of a man's *personal equation* indicates a very fundamental peculiarity of his constitution," Galton claimed that "obvious physical characteristics" were "correlated with certain mental ones." He called on astronomical observatories to become laboratories for studying the connection between *external* appearance and *internal* constitution, recommending "that a comparison of the age, height, weight, colour of hair and eyes, and temperament . . . should be made with the amount of personal equation in each observer in the various observatories at home and abroad."[84] Research on the personal equation and reaction time was part of broader investigations on bodily and racial differences.

Richard Meade Bache, a distant relation to Benjamin Franklin, argued that the speed of reaction was inversely correlated to racial and intellectual

81. Carl G. Jung, "Die psychologische Diagnose des Tatbestandes," *Schweizerische Zeitschrift für Strafrecht* 18 (1905). Republished as Carl G. Jung, "The Psychological Diagnosis of Evidence," in *Experimental Researches: The Collected Works of C. G. Jung* (London: Routledge, 1973), 325.
82. Jung, "The Psychological Diagnosis of Evidence," 341.
83. For an example of the continuation of racist conclusions reached by recent investigations, see Charles Murray and Richard J. Herrnstein, *The Bell Curve: Intelligence and Class Structure in American Life* (New York: Free Press, 1994), 284. "The consistent result of many studies is that white reaction time is faster than black reaction time, but black movement time is faster that white movement time."
84. Francis Galton, "Address," *Nature* 16 (1877). For reactions to Galton's address, see Editor, "Study of Types of Character," *Mind* 2, no. 8 (1877): 573.

superiority. In "Reaction Time with Reference to Race," he noted that "inferior races" had shorter reaction times: "The popular notion that the more highly organized a human being is, the quicker ought to be the response, is true only of the higher sphere of thought, not at all of auditory, visual, or tactile impressions."[85] This was evidenced by American Indians with "wonderfully low" reaction times. His conclusion had direct implications for current events. He agreed with the controversial decision by the famous white boxer John L. Sullivan not to fight "the colored boxer, [Peter] Jackson . . . because of his race," due to how it influenced his reaction speed in the boxing ring.

The famous psychologist Jung and others used the term "personal equation" to explain the roots of competing racial and political ideologies. In his famous *Psychological Types* (1921), Jung described a personal equation of a broader psychological nature than was commonly acknowledged: "There is also a personal equation that is psychological and not merely psychophysical." This observation led Jung to distrust the "so-called objective psychology" based on "chronoscopes and tachistoscopes and suchlike 'psychological' apparatus" and to rethink notions of objectivity: "The demand that [the observer] should see *only* objectively is quite out of the question, for it is impossible."[86] The only option was to "not see *too* subjectively," and this could only be accomplished "when the observer is sufficiently informed about the nature and scope of his own personality."[87] Jung developed various methods for obtaining this information.

Jung stressed that, if not in science, in everyday life people confronted the problem of the personal equation. Although precision measurements could be obtained at the scale of wavelengths, the fact remained that in most situations we were confronted by colors—not wavelengths. The personal equation thus remained relevant because "we see colours but not wavelengths. This well-known fact must nowhere be taken to heart more seriously than in psychology. The effect of the *personal equation* begins already in the act of observation."[88] Although by the time he was writing

85. Meade Bache, "Reaction Time with Reference to Race," *Psychology Review* 6 (1895). Charles Richet cited this article more than two decades after it was first published. Charles Richet, "Du minimum de temps dans la réaction psycho-physiologique aux excitations visuelles et auditives," *Comptes rendus des séances de l'Académie des sciences* 163 (1916). (In the article "Bache" was misspelled as "Beach"). Richard Meade Bache was a relative of Alexander Dallas Bache who led the U.S. Coast Survey and who worked on the personal equation. The low reaction time of American Indians (lower than both of blacks and whites) was an "exception" to his theory since he determined the black race to be inferior to American Indians, while both were inferior to whites.

86. Carl G. Jung, "Psychological Types," (1921), in *The Collected Works of C. G. Jung*, ed. Herbert Read et al. (London: Routledge, 1970), vol. 6. Italics in original.

87. Ibid., 9–10.

88. Ibid., 9. Italics mine.

these lines it was no longer a problem for the exact sciences, Jung argued that it remained important everywhere else.

In 1933 Jung used the term "personal equation" to explain the anti-Semitic prejudices behind the rise of Nazism, which he was often accused of sharing. Upon becoming the editor of the famous *Zentralblatt für Psychotherapie,* he described "the differences which actually do exist between Germanic and Jewish psychology" in terms of the personal equation: "The differences which actually do exist between Germanic and Jewish psychology and which have long been known to every intelligent person are no longer to be glossed over, and this can only be beneficial to science. In psychology more than any other science there is a *"personal equation,"* disregard of which falsifies the practical and theoretical findings. At the same time I should like to state expressly that this implies no depreciation of Semitic psychology, any more than it is a depreciation of the Chinese to speak of the peculiar psychology of the Oriental."[89] While in the nineteenth century the term "personal equation" had been exclusively used to describe minute differences in the measurement results of different observers, by the years preceding WWII it represented, additionally, the source of competing ideological disagreements.

Psychometrics

Another main area of application for reaction time studies was in the growing field of psychometrics or applied psychology. These experiments were enlisted for improving production in industrial and military settings.[90] During peacetime, reaction time was studied in efforts to improve industrial efficiency. During wartime, it was used to select the best soldiers.[91]

Some of the first applications of reaction time research to industry took place at the turn of the century with Frederick Winslow Taylor. Taylor

89. Carl G. Jung, "Editorial" (1933), in *The Collected Works of C. G. Jung*, ed. Herbert Read et al. (London: Routledge, 1970), 10:533–34. In German, Carl G. Jung, *Gesammelte Werke*, 10:581. Jung's followers tried to determine Jung's own equation, and that of his mentor Freud. J. Van de Hoop, a Dutch psychiatrist, included a chapter titled "The Personal Equation" analyzing Freud's and Jung's personal equation in his *Types of Consciousness and Their Relation to Psychotherapy* (1937). Cited in Shamdasani, *Jung and the Making of Modern Psychology: The Dream of a Science*, 82.

90. In a famous article John Dewey called on scientists to separate investigations on "psychical events" and those on reaction responses: "To sum up: the distinction of sensation and movement as stimulus and response respectively is not a distinction which can be regarded as descriptive of anything which holds of psychical events or existences as such." Yet on many occasions Dewey's recommendations were ignored, and reaction time research spread beyond scientific settings. John Dewey, "The Reflex Arc Concept in Psychology," *Psychological Review* 3 (1896): 369.

91. For a history of psychotechniques see Anson Rabinbach, *The Human Motor: Energy, Fatigue and the Origins of Modernity* (Berkeley: University of California Press, 1990).

used "personal coefficient" tests "regularly conducted" in the "Physiological departments of our universities" to improve industrial efficiency. In his famous *Principles of Scientific Management* (1911) he recommended "laying off many of the most intelligent, hardest working, and most trustworthy girls merely because they did not possess the quality of quick perception followed by quick action."[92] Academic experimental psychologists turned to Taylor's work to explain how *they* could expand their work to industrial contexts.

New breeds of experimental psychologists dedicated to increasing industrial and military efficiency were inspired by Taylor's reaction time methods. They complemented chronometric techniques by enlisting other technologies, including cinematography.

In France, Jean-Maurice Lahy, a scientist and soldier, was one of the main advocates of Taylorism and one of the most important contributors to the growing field of psychotechnics. In 1908 Lahy was the director of the Laboratoire de psychologie expérimentale à l'École pratique des hautes études. Lahy, together with a group of young scientists, initially gathered in the laboratory of experimental psychology at the Asile de Villejuif to work with the experimental psychologist Édouard Toulouse.[93] They formed one of the most important reaction time research centers. Closely associated with the journal *Travail Humain,* these investigators studied reaction time to understand topics ranging from dactyloscopy to train conducting. They applied their research to professional selection and professional orientation.

At the outbreak of WWI, Lahy interrupted his studies on experimental psychology and Taylorism to study gunners fighting in the Argonne region. To "completely use our human resources," war needed to be "Taylorized."[94] Hoping to optimize the efficiency of battle forces in the same way that he had previously sought to increase the efficiency of industrial complexes, he studied their reaction time. His research was complemented by the work of the medical doctors Jean Camus and Henri Nepper, who also worked with reaction time during the war. In a set of pioneering studies they tested the reaction time of aviation pilots.[95] The numbers found by these investigators

92. Frederick Winslow Taylor, *Principles of Scientific Management* (New York: Harper and Brothers, 1911).
93. Édouard Toulouse headed the Laboratoire du service départemental de prophylaxie mentale.
94. Jean Maurice Lahy, "Sur la psycho-physiologie du soldat mitrailleur," *Comptes rendus des séances de l'Académie des sciences* 163 (1916): 33, and *Le Système Taylor et la physiologie du travail professionnel* (Paris: Masson, 1916), 69–70.
95. Jean Camus and Henri Nepper, "Mesure des réactions psychomotrices des candidats à l'aviation," *Paris médical* (18 March 1916), "Les Réactions psychomotrices et émotives des trépanés," *Paris médical* (3 June 1916), and "Temps de réactions psychomotrices des candidats à l'aviation," *Comptes rendus des séances de l'Académie des sciences* 163 (1916). During WWII, reaction tests on aviation pilots were incorporated into air force selection processes.

were much higher than those in Lahy's frontline experiments, but the extraordinary conditions under which the latter were made explained the discrepancy. Lahy's subjects fought for eighteen months in French lines that frequently came to within 50 meters of the German lines. A sympathetic reviewer of Lahy's work explained how "a minimum distraction could cost them their lives. These men had to evade a bullet as well as a trench shell or a few grenades. It is understandable that, under such conditions, these soldiers showed themselves ready to act with a singular vigor, in order to escape by their motor ability and the promptitude of their movements the perpetual swords of Damocles suspended over their heads!"[96]

At the war's end, Lahy returned to his original mission of improving industrial efficiency. He became the head of a new laboratory of psychotechniques in the Parisian transportation industry (Société des Transports en commun de la Région Parisienne, or S.T.C.R.P.) with more than thirty thousand employees under his direct supervision. Lahy built complicated machines to test the professional aptitudes of bus and tramway drivers by measuring their time of reaction.[97]

Lahy reacted against the use of the term "personal equation" for these studies. He noted how "W. Taylor gave the name of personal equation of an individual to that which we call reaction time" and asked, "Can we really call personal equation the duration of reaction time?"[98] He repudiated the term because it "presupposed that all the psychological characteristics of an individual intervene in its determination."[99] He separated the two terms, narrowly defining reaction time with military, industrial, and commercial concerns and associating the personal equation with psychology more broadly.

96. Octave Grimaud, "L'Examen psycho-physiologique des soldats mitrailleurs," *La Science et la vie* 13, no. 36 (1917–18): 125.
97. A driver under examination sat in the conductor's seat of a life-size bus replica. Three-hundred meters of film, designed to give the impression that "he was in a moving car," were projected unto a screen in front of him. The films used in these tests were specifically designed to "captivate their attention and move them emotionally." Others were composed of "cinematographic scenes [that] were changing, without a thread, such as the spectacles of the street seen through a car that moves and the memories that can present themselves to the spirit of a worker, even in the course of his shift." During the course of the spectacle, the candidate was asked to react to colored lights and sirens coinciding with certain cinematographic scenes. The time needed to react to these signals and film events was then recorded automatically. The best drivers were thus scientifically culled, and the proper functioning of modern transportation networks was assured. Jean Maurice Lahy, *La sélection psychophysiologique des travailleurs* (Paris: Dunod, 1927), 155, 72.
98. Taylor used the term "personal coefficient."
99. Lahy always insisted that reaction time was not the sole determinant of industrial efficiency. He criticized Münsterberg for believing that a "single test" could be used to analyze performance in a particular field and insisted on having a "plurality of tests." Lahy ignored that the critique of basing analysis solely on reaction time had already been leveled by Münsterberg, who proposed additional tests to measure attention. On Münsterberg's error, see ibid., 15. On a plurality of tests, p. 214.

Cultures of Reaction

The importance of reaction time spread from industry and the military to other areas of modern life, characterizing its fast-paced task orientation. In *The Will to Power,* a book attributed to Friedrich Nietzsche, the author lamented how in modern times "men unlearn spontaneous action, they merely *react to stimuli* from the outside."[100] Joseph Jastrow, author of the *Time-Relations of Mental Phenomena* (1890), illustrated the pervasiveness of modern, stimulus-response behavior:

> A great variety of actions may be viewed as responses to stimuli. There is a flash of light, and we wink; a burning cinder falls upon the hand, and we draw it away; a bell rings, and the engineer starts his train, or the servant opens the door, or we go down to dinner; the clock strikes, and we stop work, or go to meet an appointment. Again, in such an occupation as copying, every letter or word seen acts as a stimulus, to which the written letter or word is the response; in piano playing, and the guidance of complicated machinery, we see more elaborate instances of similar processes. The printer distributing "pi," the post-office clerk sorting the mails, are illustrations of quick forms of re-action, in which the different letters of the alphabet or the different addresses of the mail matter act as stimuli, and the placing them in their appropriate places follow as a response. In many games, such as tennis or cricket, the various ways in which the ball is seen to come to the striker are the stimuli, for each variation of which there is a precise and complex form of response in the mode of returning the ball. In military drill the various words of command are the stimuli, and the actions thus induced the responses; and such illustrations could be multiplied indefinitely.[101]

The American experimental psychologist Edward Wheeler Scripture described the widespread consequences of reaction time. To illustrate its dangers, he imagined grouping the most important political figures of the time (including Queen Victoria and Lenin) next to each other to form a chain. If one of them perceived a stimulus, it would touch another one, who would then touch another one, and so on. This model illustrated how reaction times of the order of a tenth of a second accumulated to trigger a "chain reaction" with significant, perhaps disastrous, political consequences.

100. Friederich Nietzsche, *The Will to Power,* trans. Walter Kaufmann and R. J. Hollingdale (New York: 1967), 47. Italics mine. Cited in Jonathan Crary, *Suspensions of Perception: Attention, Spectacle, and Modern Culture* (Cambridge, Mass.: MIT Press, 1999), 53. This aspect of modernity has been a source of criticism for the New Left. See Max Horkheimer, "The End of Reason," in *The Essential Frankfurt School Reader,* ed. Andrew Arato and Eike Gebhardt (New York: Continuum, 1982), 38.

101. Jastrow, *The Time-Relations of Mental Phenomena,* 4.

Figure 2.6. "Reaction chain" showing important political figures of the time: Lenin, Queen Victoria, etc. From Edward Wheeler Scripture, *Thinking, Feeling, Doing* (Meadville, Pa.: Chautauqua-Century Press, 1895), p. 39.

In 1934 the famous writer Aldous Huxley described a brave new world of reaction time in his travels in South America. Upon seeing two American ethnologists at work, he described the plight of their Guatemalan subjects: "Utterly miserable, but resigned, like sheep being led to the slaughter, half a dozen Indians permitted themselves to be taken, one by one, measured, weighed, tested for their reactions, inked for finger-prints. The spectacle was ludicrous and pathetic. It was absurd that people should make such an agonized face about so little. Absurd, and yet the agony was obviously genuine. These poor creatures really suffered from being just looked at."[102]

Instituting the "Standard Account"

Why, if the significance of reaction time and personal equation studies often spread beyond astronomy and experimental psychology, did most scientists see them largely in light of the 1796 incident between Maskelyne and Kinnebrook? The institutionalization of the "standard account" was due to Théodule Ribot, recipient of the first chair of experimental psychology and its main representative in France. Ribot's fame slowly eclipsed that of Charcot. In contrast to the notorious doctor from the Salpêtrière, Ribot defended a new type of psychological practice, which would eventually be

102. Aldous Huxley, *Beyond the Mexique Bay* (New York: Harpers and Brothers, 1934).

called experimental psychology and which was largely based on reaction time experiments. According to Ribot, reaction time studies could shed light on "l'ennui, le taedium vitae," which he considered to arise from a "languor of mental life."[103] They could be used to study "idiots," "cretins," "certain paralytics," and conditions where "the speed of thought" was considered to be remarkably slow.[104]

Ribot was essential in establishing reaction time experiments as post-Kantian. According to him, these new techniques helped rid psychology of the limitations imposed by harmful "kantian doctrines."[105] He actively criticized the "vagueness" of Kant's theories, "which left thought in a sort of mystical region where it seemed inaccessible to measurement, with respect to its duration."[106] The timed, temporal reactions to stimuli of an experimental subject were seen as opening a door toward increased quantification in the human sciences. A distinct breed of scientists saw themselves as finally prostrating the mysterious Kantian a priori. They saw themselves as rewriting the boundaries between physics and metaphysics and between the human and exact sciences.

Ribot added further pieces to the story of Maskelyne.[107] He proposed the claim, which has since then become a well-known trope, that the systematization of reaction time experiments was "for the most part" performed by German scientists and most systematically by Wundt. Ribot argued that French scientists had a slow awakening to the potential of reaction time studies. The fact that France had to wait until 1885 to obtain a new chair of experimental psychology at the Sorbonne and for the formation of the Société de psychologie physiologique has since been often cited as evidence of the discipline's underdevelopment.[108] To this day, the history of experimental psychology is usually traced to Germany, to Leipzig and to Wundt.[109]

103. Théodule Ribot, *La Psychologie allemande contemporaine (école expérimentale)* (Paris: Libraire Germer Baillière et Cie, 1879), 300.

104. Ibid.

105. Johann Friedrich Herbart (1776–1841), who filled the chair vacated by Kant in Königsberg, became the aim of similar criticisms. For criticisms of Kant and Herbart by Ribot see Robert H. Wozniak, "Théodule Armand Ribot: German Psychology of To-Day," in *Classics in Psychology, 1855–1914: Historical Essays* (London: Thoemmes Continuum, 1999; originally published, 1879; originally published in English, 1886).

106. For his criticisms of Kant, see Ribot, *La Psychologie allemande contemporaine (école expérimentale)*, 333, 64.

107. For Ribot on Maskelyne, see Théodule Ribot, "De la durée des actes psychiques d'après les travaux récents," *Revue philosophique de la France et de l'étranger, dirigée par Th. Ribot* 1 (1876): 268, and *La Psychologie allemande contemporaine (école expérimentale)*, 301.

108. Parot, "La Psychologie scientifique française et ses instruments au début du XXe siècle"; Danziger, *Constructing the Subject: Historical Origins of Psychological Research;* Brooks, "Philosophy and Psychology at the Sorbonne, 1885–1913"; Nicolas and Ferrand, "Pierre Janet au Collège de France."

109. Ash, "The Self-Presentation of a Discipline: History of Psychology in the United States between Pedagogy and Scholarship."

Although Ribot's neglect of French experiments was most apparent in his book on German psychology, he ignored work performed in France before and after this publication. Already in his first essay on German psychology he claimed: "The majority of works [on the physiology of sensations] have been done in Germany and are little known in France."[110]

Ribot interpreted Wundt in a manner that, according to his critics, left the philosopher-psychologist from Leipzig completely unrecognizable. His contemporaries even accused him of "inventing Wundt."[111] While in his early works Ribot included Wundt's work on aesthetics, morality, and religion, he increasingly focused on a smaller aspect of psychology and of Wundt's voluminous oeuvre. He slowly limited the vast field of German psychology to certain interpretations of the personal equation and to psychophysics, two different fields of knowledge that he increasingly classed together. Recent historians still note the strange historiographic "effect of removing from view a large part of Wundt's work, in particular his Völkerpsychologie."[112] Reaction time experiments were, in fact, never central to Wundt's own investigations. They merely constituted a preliminary and inferior entrance to the much broader field of ethics and folk psychology.[113]

A closer look at Ribot's oeuvre reveals that he ignored experimental work done in France—especially work based on alternative interpretations of

110. See Théodule Ribot, "La Psychologie physiologique en Allemagne," *Revue scientifique* 7 (1874): 553. In the next installment he tempered his earlier claim by writing: "Although [in Germany] there does not exist a proper school of psychology, and although they have not published complete and systematic treatises as the English, they have no less contributed a good number of new and truly scientific studies to psychology." Théodule Ribot, "La Psychologie allemande contemporaine: M. Wilhelm Wundt," *Revue scientifique* 8 (1875): 723. In his later work he also included the caveat that research on the duration of mental acts was "not the exclusive concern of German physiologists." Ribot, *La Psychologie allemande contemporaine (école expérimentale)*, 299. But later he would continue to proclaim Wundt and Germany as advocates of experimental psychology, and France as against it. See Théodule Ribot, "Histoire des sciences: Leçon d'ouverture du cours de psychologie expérimentale et comparée du Collège de France," *Revue scientifique* 15 (1888), and "Psychologie: La Psychologie physiologique en 1889," *Revue scientifique* 18 (1889). Other articles included Ribot, "La Psychologie allemande contemporaine: M. Wilhelm Wundt," "La Psychologie physiologique en Allemagne: M. W. Wundt," *Revue scientifique* 9 (1875), and "La psychologie physiologique en Allemagne: M. W. Wundt." In his university course on "les états inconscients," Ribot lectured on the concepts of fusion and simultaneity of sensation but again did not mention French authors, stressing instead the work of Helmholtz and Wundt. Ribot, cours, Ms. 2354, Archives de la Sorbonne, pp. 10–11.

111. Fr. Picavet, "Philosophes français contemporains, M. Théodule Ribot," *Revue politique et littéraire* 2, no. 18 (1894): 592.

112. Carroy and Plas, "The Origins of French Experimental Psychology: Experiment and Experimentalism," 77.

113. For one of the first attempts to question the association of experimental psychology and Wundt, see Arthur L. Blumenthal, "A Reappraisal of Wilhelm Wundt," *American Psychologist* 30 (1975). Also see Martin Kusch, "Recluse, Interlocutor, Interrogator: Natural and Social Order in Turn-of-the-Century Psychological Research Schools," *Isis* 86 (1995). While Ribot tried to bring German work to the French public, his German sources ironically reached him through a frenchified lens. For example, for his account on Fechner and psychophysics he followed their interpretation by Joseph Delboeuf, the Belgian psychophysicist. Delboeuf's work appeared to Ribot "clearer than Fechner's." Ribot, "La Psychologie physiologique en Allemagne," 555 n. 1.

reaction time and the personal equation. Readers criticized his focus on Germany and could not understand why he did not trace the history of experimental psychology to France. The total absence of French experimental psychology in Ribot's work astounded critics. A review that appeared in the famous *Revue philosophique* (which Ribot founded and edited) could not help but complain how "Ribot tends to confuse metaphysical psychology with French psychology."[114] His focus on Germany was clearly partisan. Since Ribot had published one book on English psychology and one on German, the bewildered reviewer asked, "Why doesn't he honor the French in the same way?"[115] While some complained of Ribot's bias, others, like Pierre Janet, who would hold chairs of experimental psychology at the Sorbonne and at the Collège de France after Ribot, lauded his strategy and called it a "testimony, in any case, of a certain perspicacity."[116]

Yet despite the prevalence of reaction time experiments in many areas of science, a frequently noted characteristic of institutional French experimental psychology was its paradoxical dearth of experimentation. Ribot held a degree in philosophy and was not trained in laboratory techniques. Although he performed almost no experiments, he—ironically—came to symbolize French experimental psychology. While disdaining philosophers as "people for whom the best part of the cake is that which they cannot eat,"[117] he did not include any laboratory practices in his course. Only when he moved to the Collège de France did he finally ask for a laboratory.[118] Unqualified for doing experiments himself, he named Henri Beaunis its director in 1889. Beaunis, however, also abandoned the laboratory a few years after his appointment and left the spoils for Alfred Binet, his assistant. In career terms, the laboratory that had already been abandoned by Ribot and Beaunis was a sinking boat. The experimentally skilled Binet eventually lost against the philosophically inclined Pierre Janet when the bid for the chair reopened after Ribot retired.

While Ribot's account was canonized, others were forgotten. Indeed, forgetting was essential for establishing experimental psychology as a distinct discipline. Other writers, including Wundt himself, found origins for

114. Thomas Victor Charpentier, "Th. Ribot.—La Psychologie allemande contemporaine," *Revue philosophique de la France et de l'étranger, dirigée par Th. Ribot* 9 (1880): 351.
115. Ibid., 355.
116. Pierre Janet, "La Psychologie expérimentale et comparée," in *Le Collège de France (1530–1930), Livre jubilaire composé à l'occasion de son quatrième centenaire* (Paris: Presses Universitaires de France, 1930), 226.
117. Ribot, 15 September 1879, Bibliothèque Victor Cousin, Correspondance de Lionel Dauriac, Vol. 4, M-R, letter no. 144-1045, p. 633, on pp. 2–3.
118. John I. Brooks III, "Philosophy and Psychology at the Sorbonne, 1885–1913," *Journal of the History of the Behavioral Sciences* 29 (April 1993).

experimental psychology that differed markedly from the ones described in the "standard account." Its origin was not always traced back to 1796, to astronomy, or to Wundt. Even Wundt reacted against the association of experimental psychology with himself and Germany, for which he blamed Ribot. Although he called Ribot's *La Psychologie allemande* a "very remarkable and clear exposition," he had one objection: "But, on only one point, the description of M. Ribot can, I believe, give ground to a wrong interpretation." Ribot exaggerated the experimental side of German psychology by considering it the "general or the only preponderant" method and by giving it an "excessively prominent" place in his book. Experimental psychology, according to Wundt, was in fact "detested" in Germany, even considered "a blasphemy."[119] But historians of psychology continued to consider reaction time experiments as foundational for German experimental psychology.

Many of Ribot's assertions were highly polemical. Did reaction time experiments herald a post-Kantian era where quantification was extended to include even the psyche? Did the personal equation reveal individual traits, such as personality, nervous constitution, age, health, educational level, mental makeup, and intelligence? How were reaction time and the personal equation related to a person's appearance, physiognomy, and race? Who and where were the French astronomers and physicists ignored by Ribot?[120] Experiments on reaction time and the personal equation were hardly absent in France.[121] The philosopher and musician Lionel Dauriac tried to include them. He reminded readers how physicists always measured the effect of transmission delays on their results, including those of reaction time: "The experiments [described by Ribot] . . . are of the same nature as physics experiments: when one experiments at Montlhéry and at Villejuif on the speed of sound, one proceeds, although on a vaster scale, as proceeds Wundt and Donders. Experimenters . . . always account for the duration

119. Wilhelm Wundt, "Préface de l'auteur pour l'édition française," in *Éléments de psychologie physiologique* (Paris: Félix Alcan, 1886).
120. When Ribot included the work of French experimenters he often ignored their own conclusions and presented their findings in manner consonant with his own interpretation. For example, he cited the astronomer Charles Wolf's claims that the personal equation could be reduced through habit and attention, but completely ignored his weightier claim that the remaining personal equation was entirely retinal. Ribot's elision of French work contrasted sharply with the influential account of the personal equation by the American psychologist Edmund C. Sanford, editor of the *American Journal of Psychology*, which focused largely on France and on the work of Wolf.
121. This experimental tradition notwithstanding, Ribot and Beaunis repeatedly asserted that experimental psychology was mainly a Germanic discipline. Beaunis kept competing French experiments on sensation out of his influential pedagogical treatises until 1888, when he dedicated to them an unflattering footnote. His veiling of early experiments performed in France was clearly successful. At the time of his death he was remembered as "the first in France to pave the way for physiological psychology." "Chronique," *L'Année psychologique* 22 (1920–21).

of nervous transmission as a forced physiological intermediary."[122] In addition to the experiments on acoustics described by Dauriac, optics, ballistics, astronomy, photometry, metrology, and measurements on the speed of light, all dealt with physiological intermediaries. The characterization of the personal equation and reaction time as measurements related to the speed of thought was frequently contested. Ribot acknowledged some of the difficulties (such as how results varied among different experimenters)—but not all. Provocatively, he claimed these "hardly mattered, since the essential has been established: the possibility of measurement."[123]

Ribot's account of precision measurement spreading from the physical sciences to the human sciences was frequently called into question. His optimistic portrayal of a revolutionary moment when even the most recalcitrant object, thought, had been conquered, contrasted starkly with the work on this topic by other scientists, characterized by debates and difficulties in the establishment of the most basic time and length measurements. These difficulties affected mundane scientific practices, such as mapmaking and navigation, the establishment of time, and the determination of the length of the meter. Additionally, they cast in doubt some of the most important constants informing scientists' knowledge of the universe.

Through reaction time and the personal equation, widespread attention to tenth-of-a-second moments spread far from astronomy, far from experimental psychology, and far from the "standard account" of their history.

122. Lionel Dauriac, "Le Mouvement philosophique: De la psychologie expérimentale en Allemagne," *Revue politique et litteraire* 17 (1879): 242.
123. Ribot, "De la durée des actes psychiques d'après les travaux récents." 287.

CHAPTER 3

THE MEASURE OF ALL THOUGHTS

An elementary cerebral vibration has a certain duration, and this duration is approximately a *tenth of a second.*

CHARLES RICHET, Nobel Prize winner and physiologist

During the second half of the nineteenth century, influential physiologists and psychologists came to the conclusion that the tenth of a second was a constitutive unit of human consciousness. One of the most important scientists who stressed the significance of this moment was Charles Richet, founder of the Société de psychologie physiologique and (later) one of the most famous scientists of France, earning the Nobel Prize in Medicine in 1913.[1] Richet started his career by studying reaction time and publishing novels under the pseudonym Charles Epheyre. By the turn of the century, he was a well-established figure and author of one of the most important textbooks of physiology. In it, under the entry for "brain," he stressed the importance of the tenth of a second:

1. Jean-Martin Charcot was president of the Society (although not actively involved). Pierre Janet and Théodule Ribot were vice-presidents, and Richet was secretary. Richet also founded the *Annales des sciences psychiques,* which later became the *Revue métapsychique.*