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ORIGINAL ARTICLE

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On the speed of different senses and nerve transmission by Hirsch (1862)

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Abstract A translation is given of Hirsch's pioneering paper of 1862 on chronoscopic experiments "On the speed of different senses and nerve transmission." Hirsch was the first (1) to use Hipp's chronoscope in scientific literature, (2) to study reaction time in connection to psychological interest, and (3) to study velocity of conduction in humans with appropriate techniques. Using Hipp apparatus, Hirsch showed differences in time for manual response (1) to auditory, visual, and tactile stimulation; (2) between observers; (3) in Hirsch's own results when fresh and when fatigued; (4) according to the locus of tactile stimulation and the hand used for response; and (5) according to whether the stimulus was expected or unexpected. Moreover, observations made on one of his colleagues relate the conduction speed in nerves, from which he concludes that the differences in reaction time were due to the varying lengths of nerves. The speed of transmission in sensory nerves was evaluated by Hirsch at about 34 m/s. This work constitutes a prelude of Donders' research on the speed of mental processes.

Introduction

Adolph Hirsch (1830–1901) was an eminent Swiss astronomer and a pioneer in the field of psychology, although he has not been recognized as an important figure in psychology (Annin, Boring, & Watson, 1968). The main reason, as we shall see, lies in the fact that his publications in psychology were few and not easily accessible. Hirsch was born on May 21, 1830 at Halberstadt, Saxony in Germany. In 1858 he accepted a position in Neuchâtel, Switzerland as the manager of the new Astronomical Observatory. (For biographical information see Montandon, 1928.) Then he became an important scientific personage in Switzerland, since he became a naturalized Swiss citizen in 1865 and was appointed professor of astronomy at the Academy of Neuchâtel in 1866. He managed the Observatory of Neuchâtel until his death on April 16, 1901. Hirsch is known in psychology (see Donders, 1865, 1868; Exner, 1873; Helmholtz, 1867; Wundt, 1874) for his famous report "Chronoscopic experiments on the speed of different senses and nerve transmission," which was presented on November 8, 1861 to the Society of Natural Sciences of Neuchâtel. The original report was published in French (Hirsch, 1862a) in the *Bulletin of the Society of Natural Sciences of Neuchâtel.* This paper was also presented to the Swiss Society of Natural Sciences in Lucerne on September 25, 1862, and an abstract was published on this occasion in the *Archieves des Sciences Physiques et Naturelles de Genève* (Hirsch, 1862b). A German translation of the original article (Hirsch, 1862a) appeared in *Untersuchungen zur Naturlehre des Menschen und der Thiere* (1863) and, according to Du Bois-Reymond (1864), in the "Centralblatt für die medicinischen Wissenschaften" (1864). These multiple presentations attest to the importance of this report at the time.

Indeed, Hirsch (1862a) was the first (1) to use Hipp's chronoscope in scientific literature, (2) to study reaction time in connection with psychological interest, and (3) to study the speed of conduction in humans with appropriate techniques. Hirsch's results were widely quoted in the literature by numerous researchers of the time working in the field of psychological measurement (e.g., De Jaager, 1865; Donders, 1865, 1868; Exner, 1873; Wundt, 1874). Therefore, this work represents a major document in the history of experimental psychology. For this reason, the English translation of this paper is a very important step towards the appreciation of Hirsch's work. It is important to note that his paper was written in the context of the determination of

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astronomer's personal equations, i.e., the individual differences in observation times of the stars (for reviews: Boring, 1957; Radau 1865–67; Sanford, 1888). In the 1820s the presence of individual differences in the timing of stellar transits stimulated the interest of astronomers in the quantitative characteristics of human activity (for a review: Boring, 1957, pp. 134–142). The focus of Hirsch's paper was to measure the speed of the physiological operations involved in astronomical operations. He explained that his purpose was to provide an absolute correction for individual errors in astronomical observations instead of merely an adjustment based on the "personal difference" between observers (relative differences), as had been the custom. The problem with astronomical observations was to determine as precisely as possible the personal equation in order to correct them (Hirsch, 1874). Hirsch was the first to use absolute corrections using Hipp's apparatus.

Indeed, Hirsch was the first researcher to publish experiments using Hipp's chronoscope. The 'Hipp' chronoscope is such an important piece of apparatus for psychological purposes that in the first edition of his "Grundzüge der physiologischen Psychologie" Wundt (1874, p. 770) presents the apparatus as an important piece of psychological measurement. The history of Hipp's chronoscope was well established by Edgell and Symes (1906). In 1842 the German Matthaeus Hipp (1813–1893), who was a watchmaker and mechanic in Reutlingen, Württemberg at the time, visited the physicist Prof. Eisenlohr at Karlsruhe, where Hipp was shown a model of the instrument designed by the Englishman Sir C. Wheatstone in 1840. (For a historical note concerning this instruments see Wheatstone, 1854). Wheatstone's instrument was essentially a clock used in gunnery to determine the velocity of projectiles. This gave Hipp the idea for his chronoscope (an account of which was published in 1848 by Oelschläger, *Oberreallehrer* at the Polyclinic at Reutlingen). Hipp improved upon the original by separating the mechanism of the hands from the rest of the clockwork, thus eliminating the error due to the acceleration of the clockwork. In a later model described by Oelschläger (1849), the vibrating spring makes 1000 complete vibrations a second, and the clock dials record 1/1000 s. Hipp's first chronoscope was supplied to Prof. Reusch of Stuttgart in 1843, but the first account that we were able to find of its use in scientific investigation is that given by Hirsch. He had the advantage of personal acquaintance with Hipp, who at this time was established at Neuchâtel as the director of the Telegraphic Factory (1860–1889) and who acted as the "subject" in Hirsch's experiments with the chronoscope. Hirsch seems to have known more about the correct adjustment of the intensity of the current than did many of the later workers. A sophisticated procedure for the calibration of the chronoscope is first described in the paper (Hirsch, 1862a), and for each series of observations there is a calculation of the probable error of individual observations (Hirsch used statistics in a way that was sophisticated for his time.)

Thus, it was in the context of astronomical measurement that Hirsch (1862a, p. 103) introduced for the first time the term "physiological time", later replaced by S. Exner (1873, p. 609) with "reaction time", defined as the time elapsing between the presentation of a stimulus and the subject's reaction to it, i.e. the total time needed for the reception of the stimulus, its conduction to the brain, volitional transmission to motor nerves, conduction in these nerves, and subsequent contraction of the muscle. Keeping the response (a hand movement) constant, Hirsch observed that the 'physiological time" varied depending on the sensory organ that was stimulated. In order to measure the reaction time to acoustical stimuli, Hirsch used an apparatus consisting of a fork which could be moved up and down. On this fork was placed a ball which fell off when a spring was pressed, causing the fork's two prongs to open up quickly. At the same time the current was interrupted by the separation of the two prongs of the fork. Subsequently, the ball hit a little wooden shelf and the impact closed the electrical circuit. For the experiments with optic stimuli, an electric spark generated by an induction coil was used. At the very same moment, the current was turned off. As soon as the spark was seen, the circuit was closed by a movement of the subject's hand. For the experiments with tactile stimuli, Hirsch used a weak induction current in measuring the reaction time for tactile stimulation. In these experiments, differents parts of the body were stimulated. As noted by Diamond (1980), Hirsch's paper reported differences in time for manual response (1) to auditory, visual, and tactile stimulation (audition fastest, then tactile, then vision); (2) between observers; (3) in Hirsch's own results when fresh and when tired; (4) according to the locus of tactile stimulation and the hand used for response; and (5) according to whether the stimulus was expected or unexpected. These results (which match accepted modern data on reaction times) were new and directly interested psychology (see Wundt, 1874; for a review at the time: Jastrow, 1890).

Hirsch also measured the speed of conduction in human afferent nerves, a question of interest in physiological literature. Based on Du Bois-Reymond's proposition made in 1845 (see Du Bois-Reymond, 1846), this topic had been investigated by Helmholtz (1850a, 1850b) on frog nerves as well as on human nerves that same year (see Schelske, 1864; De Jaager, 1865; and Helmholtz, 1867, for quotations). This literature represents an important part of the background for the work of Donders and his students (De Jaager, 1865; Donders, 1865, 1868; Schelske, 1864) on the timing of mental processes. Hirsch directly addressed the question of the speed of conduction. According to Hirsch, since acoustical and visual stimuli are received at the same distance from the brain, the conduction speed in sensory nerves cannot be determined for the senses of hearing and vision; this is possible only for sensory nerves that can be stimulated at varying distances from the brain. Only the observations made on Louis Guillaume (1833–1924), a physician, relate to conduction speed in nerves. Comparing the values found for him, the difference between the time of reaction to a stimulus applied to the left foot and to the face was .0587s. The difference was .0314 s for stimuli applied to the left hand and to the face. The two conduction times are fully in agreement with each other, since the distance from the hand to the brain is about one half the distance from the foot to the brain. Hirsch concluded that the differences in reaction time were due to the varying lengths of nerves that had to be traversed. The speed of transmission in sensory nerves was evaluated at about 34 m/s. This speed was confirmed by De Jaager (1865) and Schelske (1864) but was discussed by Helmholtz (1867, 1870) in the framework of Baxt's results (a student of Helmholtz's: see Murray, 1982). Therefore, Hirsch's paper (1862a) was cited by Du Bois-Reymond (1864) and Helmholtz (1867) as an important contribution in the field of physiology on the problem of the speed of conduction in human nerves.

Hirsch's work should have been continued but was interrupted because Hipp had only loaned the chronoscopes to Hirsch for a limited period of time. Other papers were published by Hirsch (Hirsch, 1863; Plantamour & Hirsch, 1864) in the same period but they were centered more on astronomical observations and the problem of the correction of personal equations. In these papers, he described an ingenious procedure already used in 1861 in which a pendulum moved a simulated star across the meridian of an astronomical telescope, and the time was measured between the instant of "passage" and the observer's manual response. One finding was that when the "star" moved more slowly, the response time was longer. However, published reports were written by Hirsch for several years in connection with psychological problems. For example, a detailed analysis of Donders's work (Donders, 1868) was given to the Society by Hirsch on January 28, 1869 (Hirsch, 1869). Moreover, an interesting critical review given to the Society on February 5, 1874 on Exner's work (Exner, 1873) was published (Hirsch, 1874) in the Bulletin of the Society in which he reported on personal communication with Du Bois-Reymond on the subject of the conduction speed in sensory nerves. At the time (1874), Du Bois-Reymond gave his conclusions on the variation of the speed in connection with temperature and, more generally, in connection with experimental conditions of measurement. However, new research was not published by Hirsch in connection with psychological problems after that time.

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Translation[1]

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Gentlemen,

I have invited you here today to witness a few physiological experiments on the speed of the different senses, but anticipating your surprise at seeing such experiments conducted in an astronomical observatory, I think that I should begin by explaining what led me to undertake these investigations.

Among the astronomer's instruments of precision is the nervous system of the observer himself, and just like any other instrument that we employ, it is important to assess its instrumental error, so to speak. Every time we are brought to combine observations by different astronomers, we try insofar as possible to assess what we call their *personal equation*, that is to say, the individual differences in observation time. The means used to determine this is purely astronomical. It involves the simultaneous observation of stars passing: two astronomers who would like to find their personal equations will either observe the same stars alternatively (101) in the first and second part of the reticle of the same meridian circle, or each one will observe a series of stars. In the first case, by reducing the lines observed by each astronomer to the middle line, we obtain two results for the passage of stars at the meridian, and the difference between the two is the personal equation; in the second case, we determine the accuracy of the pendulum of passage separately by the observations of each astronomer, and the difference between the two gives us the equation that we are seeking.

These methods yield relative, not absolute figures; equations, and not personal accuracy. Obviously, it would be of great interest to be able to determine the personal accuracy of each observer, that is to say, the lapse between the time when the observed phenomenon occurs and when the observer notes it. This would not only allow us to combine directly the observations made at different observatiories at different periods by astronomers who need not be compared to each other, but it would also in many cases yield results that are closer to the truth.

This new method of determining the physiological accuracy of observers has become especially desirable and at the same time possible with the introduction of electric observation in astronomy employing an instrumental measurement (by means of a chronograph) instead of the old method of assessment to subdivide seconds. Now that the observer need only close an electrical current as soon as he sees the bisection of a star, it should be possible to determine the time he requires to see it and to execute the movements of his finger.

This then, gentlemen, is the aim of these investigations, the start of which (102) I intend to share with you today and which I intend to pursue. (Having had available the devices that served in these experiments for only a limited period of time, to my great regret, I had to interrupt the experiments but I am hoping to resume them in the future.)

There is nothing either unfeasible or surprising in this attempt to subject different functions of the brain and the nervous system to methods of physics, like any other material force, since we now know from modern science, and especially from the observations made by a Neuchâtel scientist, Du Bois-Reymond, in his famous work, *Untersuchungen über thierische Electricitaet*, that nerve conduction is at bottom probably nothing

[1]Numbers in parentheses indicate the original pagination.

more than an electrical phenomenon; and another great physiologist, Helmholtz from Königsberg, has demonstrated in a classical work that the speed of nerve action, far from being comparable to the speed of light or an electric current, is not even one-fifth the speed of sound.

Without delving into the details of Du Bois-Reymond's very complicated and ingenious research or the method that Helmholtz employed in his famous experiment on nerve speed, I will limit myself here to mentioning the main result, according to which the speed of sensory nerves is approximately 61.5 m/sec. You are all familiar with the summary that Uhle gave of this research in a letter addressed to our colleague Desor, and which the latter published a few years ago in the *Revue Suisse*. We find that the time required for the brain to transmit a message to the motor nerves is at least .1s, a figure that fluctuates considerably from one person to another, and with the momentary state of mind of each individual. The speed of transmission in the motor nerves was found to be about the same as the speed in the sensory nerves (103). According to Helmholtz, the whole operation of the nervous system requires between .125 and .200 seconds.

It would be of great interest to repeat Helmholtz's experiments using a more direct method and one that can be applied to living nerves in human beings, rather than frog nerves separated from the body. I would never have considered such an undertaking, which belongs to the physiologist's field of research, if it had not been for the special aim I mentioned at the beginning: my focus, therefore, was on measuring the speed of the physiological operations involved in astronomical observations – namely sight, hearing, and the time it takes for the hand to activate electrical signals. We should be able to determine not only the mean time required for each of these senses or operations, but also the constancy or, if you will, the sureness that exists for each one of these functions. The time varies for even the most practiced observer depending on his momentary state of mind, yet how much does it vary, and is this variation the same for sight and hearing, etc. We can obtain precise answers to these questions if the measurements are repeated a great number of times. Using probabilities, we can then calculate the mean or probable error in an observation.

Let me reiterate once again that the aim of this research is to measure what can be termed the *physiological time* of sight, hearing, and the tactile sense. This time comprises three elements that are extremely difficult if not impossible to separate, namely: (1) the transmission of the sensation to the brain; (2) the time required for the brain to transform the sensation into a volitional act; (3) the (104) time of volitional transmission to the motor nerves and the execution of the movement by the muscles.

Before going into the details of the experiments, I would like to say a few words about the instrument that was used – namely, Hipp's chronoscope, two of which our colleague was kind enough to place at my disposal for a period of time. The chronoscope is basically a clock movement whose mainspring is a weight and whose regulator is one of the vibrating springs that Hipp invented, the precision of which you have been able to see at work in our chronograph. The wheels that conduct the hands are independent of the main movement and can participate in the motion of the latter or not, depending on whether a pinion is slightly advanced or withdrawn. This function belongs to an electromagnet whose frame, depending on whether it is attracted or not, withdraws or advances the pinion and thereby stops the hands or sets them into motion. The movement is calculated as follows: it takes a tenth of a second for one of these hands to make a complete revolution, and since the dial is divided into 100 parts, each part corresponds to a thousandth of a second. While the first hand goes around once, the other advances to one of the lines of the second dial, it too being divided into 100 parts. In this way the thousandths of a second can be read on the first dial and the tenths of a second on the second dial.

The experiments are conducted as follows: the observed phenomenon itself sets the hands into motion by interrupting the electrical current, and as soon as the observer perceives the phenomenon, he turns the current back on by means of a manipulator.

It is clear from this brief description of the device that the exact precision of the chronoscope will depend, to begin with, on the equivalence of the time required for the electromagnet frame to move when the current is opened or closed. In this case only, (105) will the time interval when the hands are moving correspond exactly to what we want to measure. We known that this time varies with the intensity of the currents and differs for the opening and closing of the currents. Thus, for each special instrument, we first have to determine the intensity of the current, for which attraction time and release time are equivalent. We can find this out by dropping a ball from different heights in a proportion of 1 to 4, and varying the intensity of the current until the numbers indicated on the chronoscope for the time of the fall are exactly in the proportion of 1 to 2.

Once this point is settled, we still have to determine the limits of precision of the measurements obtained with the chronoscope. It is clear to begin with that the exactness of a single measurement will never surpass a thousandth of a second, since the small fork that stops or releases the hand movement can first lean against the corner of a prong and then slide either to the left or to the right. To get an idea of the chronoscope's upper limit of error, we repeated the ball-dropping experiment many times and from the same height, and then used the deviations to calculate the mean error. The results are as follows. (106)

Ball-dropping experiment

Date 1861	No of obs.	Mean reading time s	Expected error of the mean s	Expected error of an obs. s	Comments (*)
Oct. 27	25	0.2528	± 0.0006	± 0.0029	Chrono I
Oct. 27	50	0.2515	± 0.0006	± 0.0042	Same height
Nov. 4	29	0.2014	± 0.0003	± 0.0019	Chrono II
Nov. 5	35	0.2006	± 0.0003	± 0.0017	Same height
Nov. 6	28	0.1984	± 0.0002	± 0.0011	Normal current
Nov. 6	28	0.1903	± 0.0002	± 0.0012	id.
Nov. 6	32	0.1868	± 0.0002	± 0.0011	id.

(*) The current was too weak in the first experiments

First, we can see that not only do the indications of the chronoscope vary with the intensity of the current, as we said earlier, but that the regularity of its functioning is basically dependent on it. Next, provided the correct current strength is used, the mean error of an observation never exceeds two thousandth of a second, so that twenty observations suffice to reduce the error probability to below half a thousandth.

Finally, for the sake of reducing the observations adequately, we needed to know either to what extent the chronoscope was adjusted to the mean time, or the time value of a division of the upper dial. Since I did not yet have a pendulum switch at my disposal, I calculated this using an ordinary telegraphic manipulator. Placing myself opposite the normal pendulum, and following the second hand, (107) I then turned on the current (thereby setting the chronoscope into motion) and stopped it ten seconds later. This undoubtedly introduced an element of physiological uncertainty into determining the chronoscope speed, but the error arising from this factor was first divided by the number of seconds and then further reduced by repeating the experiment, so that the exactness of the result is more than sufficient, as can be seen from the following figures.

We can see that the two devices used are very closely adjusted and that it was only necessary to apply a slight correction to the dial readings.

Let us now turn to the physiological experiments as such, starting with those that have a bearing on the sense of hearing, since they are directly connected to the ball-dropping experiment. The device employed to observe the fall consists of a kind of fork that moves up and down a vertical column and holds a ball in such a way that, when a spring is pressed, two of the fork's prongs rapidly open, letting (108) the ball fall; at the same time the current is interrupted by the separation of the two prongs. When the ball hits the shelf below, its impact closes the current. The setup can be modified so that the subject, rather than the impact of the ball, closes the current by pressing a manipulator when he hears the sound of the ball hitting the shelf. It is easy to grasp how, if we alternate the two setups and calculate the difference between the two time intervals, as indicated by the chronoscope in each case, this very difference yields the physiological time of hearing or else time required by the subject to hear the impact and to signal it with a movement of his finger.

Needless to say, the results thus obtained were first adjusted for sound transmission, since the device was situated at a distance of about 2.2 m. Next we ascertained that the movement of the manipulator lever was short enough to be negligible; and indeed, between the opening and the closing of the current by the two switches situated, as we know, at either end of the lever, the time was so short that the chronoscope was not set into motion. This comment may be applied to all of the experiments that are being discussed in this note. Lastly, it should be noted that the subject could not see the ball falling; the fork prongs were opened by an assistant, so that the sound of the impact always came unexpectedly.

Here, then, are the results of these experiments on myself and on some of my friends who were willing to participate. (109)

Determining chronoscope speed

Date	No. of exp.	Value of 10 s in dial part	Expected error of the mean	Expected error of an exp.	Value of dial part	Expected error
Chrono I						
		p	p	p	s	s (±)
Oct. 29	49	9874.4	± 0.0080	0.0562	0.001013	0.0000008
Chrono II						
		p	p	p	s	s (±)
Nov. 5	48	9895.7	0.0076	0.0526	0.0010105	0.0000008

Auditory experiment

No of experiments	Physiological time s	Expected error of the mean s	Expected error of an observation s	Observers
81	0.1490	± 0.0029	± 0.0253	Hirsch
32	0.1584			Mayer
41	0.1620			G. Guillaume
22	0.2015			Garnier
23	0.2432			Desor
11	0.2433			Hipp

We can see that the subjects differed considerably in their hearing reaction time, in a proportion of 5 to 8, and in all likelihood these differences would be even greater with other people.

I would like to make a comment about Hipp, who has a very practiced ear since he can easily follow a telegraphic wire just by listening to it; his hearing was the slowest, but there were only slight deviations from one experiment to another.

I would have liked to have investigated the nature of the noise or the sound heard, using, for instance, more or less sudden and harsh sounds, but the nature of the device and the way the experiment was conducted could not easily be adapted to this purpose. A matter that remains to be investigated is whether the perception of a rhythmic noise — as, for instance, what interests the astronomer most, namely the beat of a pendulum — would give rise to a different result, as the analogy with sight, as we will see hereafter, would lead us to suppose. (110)

Let us now turn to the experiments on sight, for which we first employed an electrical spark produced by an induction coil. The setup was as follows: the current of the chronoscope was branched into two channels, one leading to the electromagnet and the other to the induction coil; when the current was interrupted by the assistant, the chronoscope's hands were set into motion and at the same time an induction spark was produced between the two very close wires of the outer coil; as soon as the observer saw the spark (against the dark background of powdered charcoal), he closed the current by pressing the manipulator, thereby stopping the chronoscope. Here are the results of few series of observations of this type.

Sight experiment

No of experiments	Physiological time s	Expected error of the mean s	Expected error of an observation s	Observers
49	0.1974	± 0.0023	± 0.0165	Hirsch
49	0.2038	± 0.0021	± 0.0148	Hirsch
46	0.2096			Droz

The second series of experiments on myself took place several hours after the first, when my eyes were somewhat fatigued by astronomical observations. Apparently, perception speed depends on the momentary state of mind, at least within very narrow limits, a factor that will probably hold true for the other sense organs.

Observing a spark, though, seemed to me to differ too much from astronomical observations, (111) which entail capturing the passage of a moving body in relation to fixed reference points. To approximate astronomical observations, I tried to grasp the moment when the chronoscope's bottom hand passed certain marks on the dial (0 and 50, on the vertical line); when I saw the hand pass the vertical position, I pressed the manipulator causing the hands to stop and thereby obtained the time required to grasp these passages. For this purpose, I needed on the average, 61 observations;

$$\overset{s}{0.0769} \pm \overset{s}{0.0032}$$

the mean error of a single observation being ± 0.0251. It is obvious then that such a passage was seen much more quickly than an unexpected phenomenon, probably because the moment of passing can be anticipated when one follows the course of a moving body. This sense of judgment that intervenes in perception might also explain the greater degree of uncertainty that seems to exist for this type of observation compared to the observation of an unexpected light.

However, such an observation is still far from being totally comparable to the passage of a star before the lines of a telescope; setting aside all the other notable differences, the movement of the hand (which, having about 4 cm, completes its movement around the dial in 10 s) is much too fast, and this necessarily hinders the sureness of the observation. Since I am convinced that it is particularly important to measure physiological time for observing passages that wholly resemble astronomical observations, I intend to have a special device made for this research.

The experiments on the physiological time of the tactile sense are less directly related to astronomical observations (112), but they are none the less of particular interest because they enable us to separate to a certain extent the first element of physiological time and to measure the speed of transmission in the sensory nerves by stimulating spots at varying distances from the brain. To create this stimulation I made use of a weak induction current producing a sensation resembling a slight prick of a needle, rather than a jolt. Needless to say, the same current, by being interrupted, generated this weak induction current and set into motion the hands of the chronoscope; the subject stopped the hands when he felt the current which I applied to different parts of the body using a specially devised electrical tong. I first conducted the experiments on myself, stimulating my left hand by touching both ends with my second and fifth fingers while using my right-hand to press the manipulator. In the experiments with Dr. Guillaume the current was first applied to the infraorbital area of his face, then to his left hand, and finally to his left foot. Here are the results.

Tactile experiment

No of experiments	Physio logical time s	Expected error of the mean s	Expected error of an observation s	Observers
41	0.1733	± 0.0027	± 0.0176	Hirsch
43	0.1911	± 0.0022	± 0.0142	Hirsch
57	0.1110	± 0.0018	± 0.0140	Guillaume[a]
59	0.1424	± 0.0028	± 0.0219	Guillaume[b]
61	0.1697	± 0.0029	± 0.0229	Guillaume[c]

[a] current applied to the face
[b] current applied to the left hand
[c] current applied to the left foot

(113) The notable difference exceeding the error of the mean in the two series of observations on myself can be explained in part of the fact that during the second series the current was weaker, and at the same time my attention was more strained. On examining the figures concerning Dr. Guillaume, we see that the difference of transmission between the face and the left foot is .0587 s, and the difference from the face to the left hand is .0314 s, which concurs perfectly since the distance from the hand to the brain is slightly more than one half the distance from the foot to the brain. This agreement and the differences between the three series, which greatly exceed the error of the means of each one separately, seem to suggest that we can account for the differences by the different lengths of the nerve transmission path. It is possible, however, that the internal parts through which the current passes differ in sensitivity, which in addition to the distance from the brain, could contribute to modifying the physiological time. With this qualification in mind and assuming that the length of the nerve transmission path from the foot to the brain is 2 m long, the speed of transmission in sensory nerves could be evaluated at about 34 m/s.

I give this figure, however, as an initial approximation subject to confirmation by more numerous and more varied experiments, in terms of subjects as well as the parts of the body tested. The difference between our figure and Helmholtz's is not surprising, insofar as the method of experimentation differed radically and, more especially, Helmholtz operated on motor nerves separated from the body of the frog, while our result was obtained on human sensory nerves in their normal state. Since the method we developed is preferable in this (114) respect, it is to be desired that physiologists will apply it and develop it further than I could hope to do. I would like to make one further comment before leaving this subject: the errors of the three series of experiments on Guillaume seem to indicate that the tactile physiological time varies as a function of the distance of the stimulated spot from the brain. We are led to this assumption in particular by the notable difference between .014 s for the face and .022 s for the hand.

In conclusion, here is a summary of the results that I have obtained until now for the different senses.

	Physiological time	Mean error
1. Hearing	0.149 s	± 0.025 s
2. Sight (spark)	0.200 s	± 0.016 s
3. Sight (passage)	0.077 s	± 0.025 s
4. Tactile (left hand)	0.182 s	± 0.016 s

One can see that the observation of an unexpected, sudden phenomenon takes the longest time, about one third more than hearing, while the observation of a passage is accomplished much more quickly. On the other hand, the precision or the the regularity of sight is greater than hearing in a ratio of two to three, while observing a passage is subject to the same uncertainty (.025) as hearing. For the tactile sense, the mean error of an observation is the same as for sight.

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