I wish to add one last word, on the desirability of printing the name of the author of the species following the scientific plant or animal name. I labored for years to secure this obviously just custom with one important bibliographical publication before the publishers were convinced of its importance.

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SCIENTIFIC BOOKS

Stars and Atoms: A. S. EDDINGTON, Sc.D., F.R.S., Plumian Professor of Astronomy in the University of Cambridge. New Haven: Yale University Press. London: Oxford University Press. pp. 127.

IN "Stars and Atoms" Professor Eddington has given us one of the most valuable and delightful monographs on astronomy that has ever appeared in the literature of science.

The rapid strides of physics and chemistry into the realms of the stars have fairly bewildered students of the older astronomy, and it is a remarkable service which the author has rendered in giving to the general reader, without mathematical details, the essential problems of modern astrophysics. With a sufficiently extensive description of the atom and its ionization that will enable the general reader to picture the mechanism of radiation and radiative temperature, the author portrays the essential make-up of the sun and stars and makes clear the problem of the maintenance of their heat.

When one reads the all too often dogmatic statements concerning recent advances in astronomy, one feels refreshed in finding so great an authority as Dr. Eddington sounding notes of caution while making sharp distinctions between the demonstrable and the speculative.

The saving sense of humor which relieves the dilemma in many an embarrassing scientific situation keeps the reader in friendly terms with the scientist, even in his wildest guesses and in the end fosters a genuine faith and confidence in results of notable significance.

In few books, indeed, does one sense more acutely the true spirit of science in its never-ending quest for divining the nature of things. From the first chapter to the last the reader is carried at almost breathless pace through round after round of astrophysical discovery till he is introduced to matter in all but unbelievable states as it exists in the companion to Sirius.

In his final chapter on stellar evolution, Dr. Eddington makes a strong argument for the annihilation of matter through the radiation of mass, but does not overlook such technical details and perplexities as the simultaneous existence of giant and dwarf stars in coeval clusters, the problem of devising laws for the release of subatomic energy consistent with the demands of astronomical observations and at the same time reconcilable with any satisfactory picture of the annihilation of matter which the student of subatomic activity can postulate.

A lesser scholar than Eddington would not have closed the book with an anticlimax. It is a mark of genius and modesty worthy of a successor to the traditions of Newton that his closing paragraph should read:

> I should like to have closed these lectures by leading up to some great climax. But perhaps it is more in accordance with the conditions of scientific progress that they should fizzle out with a glimpse of the obscurity which marks the frontiers of knowledge I do not apologize for the lameness of the conclusion, for it is not a conclusion. I wish that I could feel confident that it is even a beginning.

H. T. STETSON

SPECIAL ARTICLES

THE CORRELATION BETWEEN INTELLIGENCE AND SPEED IN CONDUCTION OF THE NERVE IMPULSE IN A REFLEX ARC

THE present paper is a preliminary report of a study to determine if there is any relationship between the factors of intelligence and reflex time or speed in conduction of the nerve impulse in a reflex arc.

My work of the last three years as a fellow of the National Research Council has centered around an investigation of the neural processes in stuttering, and there has developed out of this research a refined technique for utilizing action current measurements in functional neuromuscular derangements. In studying certain reflexes during stuttering among patients widely different in intelligence an apparent relationship between reflex time and intelligence or mental ability was noted. These observations were verified on the patellar tendon reflex. Nearly all the excellent work that has been done on this reflex has involved so-called gross reflex time or the time elapsing between the application of the stimulus and the movement of the foot or thickening of the muscle. This gross reflex time probably would not correlate very highly with such mental factors as we wish to study because nine tenths of the time is taken up by movement of the muscles in extending the foot and any factor affecting the central nervous mechanism

would be masked. Our technique provides a means of determining the length of time elapsing between the stimulation of the patellar tendon and the production of the action currents in the muscles, which is about one tenth as long as the gross reflex time. In other words, it permits the measurement of speed of conduction in a reflex arc.

We secured a group of forty-four individuals ranging in mental ability from feeble-mindedness to that of very superior university men and gave the Otis test of mental ability, Higher Examination, Form A, which has a reliability coefficient of .921. The correlation between the scores on this test and the reflex times was found to be .87 with a probable error of .024. The bright individual has a short reflex time, while the dull individual has a long reflex time. This high correlation is really astounding inasmuch as we are undoubtedly dealing with an imperfect measure of intelligence. Even if the test scores represented absolute measurements of intelligence we could not expect a higher correlation. We therefore took every precaution to verify our findings both on the instrumental side and on the side of intelligence rating. We looked about for other criteria of alertness or intellectual responsiveness and also for a group of individuals which presented a fairly normal distribution of these mental characteristics. Forty-three university freshmen on whom the University of Iowa qualifying examination scores were available were selected to fulfill the above requirements. This examination aims to measure the ability of a student to do college work. The correlation between the University of Iowa qualifying scores and the reflex time again turned out to be .87 with a probable error of .025. The two correlations being equal is an element of chance. The correspondence between the intelligence ratings and the reflex times was very close, not only for widely separated individuals but for the intermediate subjects as well.

The mean score on the Otis of the forty-four subjects was 53.9 as compared to 53.0 obtained on 2,516 college students reported by Professor Otis. The range of our group was from thirteen to seventy-five as compared to the range of his group, twenty to seventy-five.

The mean score of the forty-three freshmen in the university qualifying examination was 362.0, which is approximately the mean of all freshmen students. The range of our group was the same as that of the entire freshman class inasmuch as every tenth student, which included the highest and the lowest, was selected from a list arranged in the order of percentile rank.

The apparatus finally developed to obtain the reflex time in the knee-jerk consisted of a three-stage, resistance coupled amplifier, a portable, three-element oscillograph, a vacuum-tube oscillator, a mechanical stimulating mechanism and a signal circuit.[1]

The amplifier furnished medium amplification and was exceptionally free from inherent disturbances. The oscillograph is manufactured by the Westinghouse Electric and Manufacturing Company. The element which recorded the action currents was approximately ten times as sensitive as the other two standard vibrator elements which furnish the signal and the time lines. A special photographic unit was devised to replace the one with which the oscillograph was originally equipped. This specially built unit will handle four hundred feet of moving picture film.

The oscillator is a General Radio Company product and was used to furnish a time line of a thousand complete cycles per second. The stimulating mechanism described elsewhere[2] delivered blows of constant intensity and at a uniform rate of six per minute. The signal circuit was actuated by discharging a condenser which had been charged previously.

The electrodes were German silver plates, twenty-seven millimeters in diameter, covered with canton flannel, which was soaked in a saturated saline solution before each experiment. One electrode was placed over the place where the femoral nerve enters the rectus femoris muscle which, according to an unpublished study by Tuttle and MacEwen, is half way between the superior margin of the patella and the anterior superior spine of the ilium. The second electrode was placed peripherally about six inches from the first. Control experiments have shown that the amplifier is stable and able to respond instantaneously to changes in potential impressed on the input.

The subjects were comfortably seated, with the thigh slightly elevated to put some tension on the quadriceps muscles. An explanation of the manner in which the experiment was going to be carried out was given to each subject in order to dispel any fears he might have of being shocked or injured. Care was taken also to select individuals who were not fatigued and who had not been ill recently.

Reflex time is determined in a record by ascertaining the length of time elapsing between the instant of application of the stimulus to the patellar tendon and the arrival of the action currents at the first electrode. Reflex times are read and reported in thousandths of a second. At least eight records were obtained on each subject.

[1] Theodore A. Hunter is to publish elsewhere a technical description of this set up.

[2] Tuttle and Travis. "A Comparative Study of the Extent of the Knee-jerk and the Achilles-jerk." *Am. J. Physiol.* 82, 1927, 147.

All reflex time experiments were made and the records read in ignorance of the results from the intelligence tests. Also fifteen records were selected at random and read by a disinterested person. The agreement between the two readings was practically perfect.

The mean reflex time of the forty-four Otis cases was .0194 seconds. The range was from .0114 to .0268 seconds. The mean reflex time of the forty-three university freshmen was .0197 seconds. The range was from .0154 to .0245 seconds.

Each group gave a fairly normal distribution in reflex time. The great individual differences in reflex time are considered as very important. It varied from 11/1000 to 27/1000 of a second. In other words conduction over a reflex arc in one individual was two and a half times as fast as conduction over the same reflex arc in another individual.

These marked differences in reflex times found in our groups are probably referable to differences in synaptic resistances in the arcs and not to differences in resistance of the nerve trunks. Just how much of the nervous system is involved in the patellar tendon reflex is a debated question, but a recent study by the writer[3] showed that the action current records during the knee-jerk were practically identical with those during voluntary extension of the foot. Both sets of records gave indication of two different rates of discharge, one furnishing the audio or principal frequency of from three hundred to six hundred oscillations per second, and the other, the modulating inaudible frequency of from eight to twelve per second. This slower rate of discharge is probably from the Betz cells in the precentral cortex and would indicate that the higher centers are involved in the knee-jerk. If this is true we are dealing with a considerably greater number of synapses than is commonly thought of in this connection and a larger fraction of the nervous system as well.

Although the individual differences in rate of conduction in the reflex arc we have been studying are great they take on real significance when viewed in connection with the complicated associational paths of the cerebral cortex which probably function in the higher mental processes.

We are here confronted with a new fact—a fact which has become available by the refinement of technique in measurement. It challenges us to reinvestigate all the generally recognized phenomena of this particular reflex. It opens up an unlimited vista of inquiries into the nature of its cause, the conditions under which it varies, and its meaning in psychological and physiological terms. It is conceivable that we are here dealing with a relatively complex reflex arc—perhaps more complex than has been suspected, and it is fair to assume that it is typical of a large number of reflex arcs which constitute an integrated central nervous system. Now, according to the best modern theories of intelligence the cognitive processes may be thought of as hierarchies of reflexes of which the vast majority are perhaps at as low a level in the central nervous system as that of the patellar reflex. If this is true, we have in the type of conduction through the patellar reflex arc a sample of the type of conduction that takes place in all well organized motor life and possibly, as these facts indicate, also the cognitive. Tests of intelligence have always stressed the element of speed and this is perhaps right, because an intelligent response to a complex situation may conceivably be thought of as a prompt response, radiating into a large number of systems. We may think of the central arcs of an individual as having a personal equation, just as we do in a gross way when we observe one man is quick and another is slow in his movements, even in his thought movements.

Whatever the interpretation through further study may prove to be, we have in this concept of the rate of conduction through a central arc, a new approach to the neuro-physiology of intelligence or mental alertness.

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[3] Travis, Tuttle and Hunter. "The Tetanic Nature of the Knee-jerk Response in Man." *Am. J. Physiol.* 81, 1927, 670.

A COMPARISON OF GROWTH CURVES OF MAN AND OTHER ANIMALS

IN connection with investigations on the time relations of growth of domestic animals, several charts have been prepared on the growth of man. The purpose of this article is to present four of the most striking, or the most instructive, charts together with a few comments. For a background to this work and for details of technique the reader is referred to a series of Research Bulletins which are being published by the University of Missouri Agricultural Experiment Station (Columbia, Mo.).

Figure 1 represents an equivalence chart for growth of man and animals. It represents growth equivalence only for the phase of growth following puberty. This chart serves to illustrate the fact that the difference between the growth curve of man and that of any other animal under consideration is infinitely greater than the difference between the curves of widely separated species of animals. The growth curve of man is, quantitatively viewed, in a class by itself, unless it is found to be related to the curves of other primates. This figure suggests the following comments: