Equation (3) is also for a power function (but in which the exponent is negative). The values of the constants are easily obtained from the data. Here again the constant which describes the character of the process is found experimentally to be practically invariable (about -0.3) over a wide range of conditions and with different animals.

Discussion of the process underlying the conditions of facilitation of these eating reflexes (other than to note that it must obey the power law) may be delayed until the possibilities of this method have been more fully utilized.

THE ENERGY REQUIREMENTS OF INTENSE MENTAL EFFORT

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The popular tradition that fish is a brain food has given way to the idea that mental effort demands calories. It is the experience of nearly every one that intense, sustained mental effort results in a feeling of profound fatigue, not only in mind but likewise in the entire body. The disposition instinctively to seek fresh air, to open a window and to stretch the limbs after a period of mental work is pronounced. Is the effect of mental effort upon the general vital processes in any sense commensurate with this subjective feeling of profound fatigue? The problem has been an alluring one and contributions have been made to it intermittently for thirty or more years. At the present day, although the results are most divergent, the consensus of critical opinion is that mental work has somewhat of an influence upon the metabolism, that the effect varies with the intensity of the work, and that there is a great difference in the effect produced by various kinds of mental effort. The factors most readily and most clearly studied in their relation to mental effort are the pulse rate, the respiration rate and, indeed, the entire mechanics of respiration, the carbon-dioxide production and the oxygen consumption. Measurement of these last two factors gives a direct means for computing the total energy transformation or the metabolism.

In any experimental procedure the ideal situation would be to measure the metabolism when the subject is in digestive repose, i.e., 12 hours after the last meal, perfectly quiet, muscularly relaxed, and as nearly as possible in a state of mental vacuity. Upon this basal condition should then be superimposed the factor of intense mental activity. Since this superimposed factor introduces the element of "attention" or alertness, one first seeks to study the influence upon metabolism of simple attention without an excessive amount of mental activity. Simple attention means the receptivity of the mind and the reaction either by finger movement or by speech to an auditory stimulus, such as an electric bell or a buzzer, or to an ocular stimulus, such as red and white lights appearing in the field of vision, the subject showing his discrimination between the colors by pressing a telegraph key once for the white light and twice for the red. Neither of these reactions calls for particular mental effort, and yet both do introduce the element of attention with slight discrimination. Finally, there is the question of the mental effort itself. A glance at the literature shows that innumerable attempts at studying mental effort have been made, ranging from the simple reading of a daily paper to complicated mathematical calculations by mental operation solely. Learning of nonsense syllables and memorizing passages that are being read are other types of mental work. But, according to all the earlier literature, the common opinion is that mental arithmetic problems in simple multiplication call for the most sustained and intense effort and the effort made in such problems can be approximately quantitated.

In our series of experiments we measured the metabolism, first, during as nearly as possible complete muscular repose and with mental vacuity, then during "attention," and finally during mental effort, consisting usually in the solving of arithmetic problems such as the multiplication of two figures by two other figures, the whole process being carried out mentally. For our subjects we had 6 different individuals, one woman (subject VI) and 5 men, all of whom we required first to become well accustomed and trained to the technique for measuring the respiratory exchange, before we began our study of the effect of mental effort. To measure the respiratory exchange, we employed as a breathing appliance a helmet which, for the first time in such studies, permits free vision with no discomfort from holding a mouthpiece or wearing a nose-clip. Subjects can wear this helmet without previous training for two or three hours at a time with perfect comfort. Under these conditions we have the least interference with mental operation.

The heart rate was directly obtained by means of a cardiotachograph of Dr. Ernst P. Boas, of the Montefiore Hospital, New York. With this instrument each heart beat is magnified by radio amplification and is recorded, entirely unknown to the subject, on a smoked drum, along with time marks. The respiration rate and the depth of respiration were recorded by writing on a kymograph drum attached to the spirometer, into which the subject breathed. The respiratory system that we used consists of a closed air-circuit, including the helmet, which is made airtight around the neck by means of a light-weight bathing cap. A rotary blower withdraws the air from the helmet, passes it through an absorbent for carbon dioxide, and returns the air to the helmet carbon-dioxide-free. The oxygen absorbed by the subject is replaced by a fresh supply, introduced through a meter. The spirometer provides for the expansion and contraction of air in the closed system with each respiration, and the pointer on the counterpoise of the spirometer writes the characteristic respiratory curves on a revolving kymograph drum. The oxygen consumed is measured directly by the meter. In most of our experiments the carbon-dioxide production was likewise determined by weighing the vessel for absorbing carbon dioxide at the beginning and end of each period of measurement.

In another series of experiments the respiratory system was ventilated by passing outdoor air deprived of carbon dioxide into the helmet, withdrawing the expired air by the blower, passing it through a calibrated meter, and drawing an aliquot sample for analysis on the extremely exact gas-analysis apparatus of Dr. T. M. Carpenter. In many instances the two methods were combined, the carbon-dioxide production and the oxygen consumption being determined by weighing the absorbers, by gas analysis and by the meter readings. In all cases the agreement in the results was perfect.

In a typical experiment the subject, not having eaten since six o'clock the evening before, comes to the Laboratory, lies down quietly in a quiet room, covered with blankets, the electrodes are adjusted over the heart, the helmet is placed on the head, and the ventilation immediately begins. At times, entirely unknown to the subject, the absorbing vessels are changed, samples of the expired air are taken, and thus measurements are obtained as frequently as desired. During the basal periods the subject is cautioned to remain perfectly quiet and tranquil, and to engage in no mental work. The difference between the type of mental effort made during the second part of the test and that ordinarily existing in a person lying quietly on a sofa is so great, however, that no matter what the mental activity of the subject while lying in the preliminary experiments, it is so infinitely less than that called for in the mental work periods that the preliminary experiments may still serve as a base line, even if the subject is not in an ideal state of mental vacuity.

Following the rest periods the subject is asked to respond to some stimulus, either ocular or auditory. This stimulus consists of flashing lamps or more commonly of ringing a simple buzzer. Each time the lamps are flashed, the proper lamp and the subject's response are recorded on the kymograph, so that the discrimination as well as the time for the response can be recorded graphically. This test showed in all cases that our subjects were duly attentive. Similarly, with the buzzer the responses invariably coincided with the stimuli.

The "attention" periods were succeeded by several periods of mental activity. The first one, consisting usually of about 10 minutes of mental effort, was termed a "preliminary period." This was followed by three or four 15-minute periods of sustained mental effort. The mental effort consisted in solving, without writing or talking aloud, certain multiplication problems, a typical one being to multiply 76 by 69. The investigator gave the problem verbally, in a clear voice. A new problem was given as soon as the subject indicated by a tap on the telegraph key that the previous one was solved. Three or four 15-minute periods of such mental activity followed each other in succession. Then the problems ceased, and there were periods either with no stimuli or with the buzzer stimulus. Occasionally, after two or three periods of repose there was a second series of periods (two or three in number) with mental effort, followed again by periods of repose.

Perhaps the most pronounced result was the rather striking change in the mechanics of respiration. The depth and the rate of respiration, which during the periods of repose were very regular, were greatly altered by the superimposition of the mental effort and became noticeably irregular. Measurement of the height of each respiratory expiration on the spirometer curve made it possible to sum up the total volume of air passing through the lungs, and it was found that usually there was an increased respiratory volume during the mental work. (See table 1.) The respiration rate per minute, however, increased but insignificantly during the mental work. The heart rate was increased on the average five beats per minute, although the woman (subject VI) showed an increase of 12 beats per minute.

TABLE 1

EFFECT OF MENTAL EFFORT ON THE HEART AND RESPIRATORY ACTIVITY

(Average values per minute)

SUBJECT	HEART RATE REST	HEART RATE WORK	RESPIRATION RATE REST	RESPIRATION RATE WORK	VENTILATION OF THE LUNGS REST LITERS	VENTILATION OF THE LUNGS WORK LITERS
I	62	64	15	16	5.2	5.7
II	55	61	15	18	5.5	6.3
III	60	62	14	16	5.0	5.6
IV	54	57	15	15	7.2	7.7
V	73	77	17	15	5.8	6.7
VI	55	67	10	11	3.9	5.0
Average	60	65	14	15	5.4	6.2

The repose periods following mental work indicated in all instances a tendency for a return to the original respiration rate and depth of respiration and a return to the original heart rate. The results of the second mental work series duplicated in most part those of the first. There was no indication of a summation effect or of a greater increase in the second mental work series over the first. Furthermore, during the progress of the one hour of mental work (four 15-minute periods) there was no evidence of any greater effect upon the respiratory and the heart activity during the later periods than during the first period (which followed an adjustment period of 10 minutes).

Of greatest physiological interest, however, is the measurement of the gaseous exchange, which in turn permits the calculation of the energy transformations. As has been found in innumerable earlier results, the carbon-dioxide production per minute was invariably somewhat increased during the mental work. (See table 2.) But this of itself does not necessarily indicate a true increase in metabolism, for with a marked change in the mechanics of respiration one could easily expect a draft upon the

TABLE 2

EFFECT OF MENTAL EFFORT ON CARBON-DIOXIDE PRODUCTION

(Cc. per minute)

SUBJECT	I	II	III	IV	V	VI
Rest	178	173	174	202	149	139
Work:						
Period 1	183	197	184	210	168	159
Period 2	183	179	185	205	160	156
Period 3	180	177	183	209	159	157
Period 4	178	179	...	...	...	160

relatively large amounts of previously formed carbon dioxide stored in the body, and hence an increase in the exhalation of carbon dioxide without a relative increase in the metabolism itself. The general course of the carbon-dioxide exhalation was, however, an increase in the mental work periods, followed by a decrease in the return to rest and again an increase in the second series of mental work periods. There was no cumulative effect in this increase, for at the end of an hour (usually divided into four 15-minute periods) of severe mental effort the amount of carbon dioxide exhaled was not greater than during the first 15 minutes.

TABLE 3

EFFECT OF MENTAL EFFORT ON OXYGEN CONSUMPTION

(Average cc. per minute)

SUBJECT	REST	WORK
I	208	210
II	212	219
III	232	241
IV	242	247
V	174	187
VI	181	191
Average	208	216

It is in the oxygen consumption that we have the greatest interest, for the oxygen consumption represents more nearly the true increase due to oxidative activities or metabolic processes as a result of any superimposed factor. In general, in the mental work periods (see table 3) there was a slight increase in the oxygen consumption, usually not as great as in the carbon-dioxide production but nevertheless a positive increase, followed by a decrease in the rest periods and an increase again during the second series of mental work periods. It thus appears that the oxygen measurement indicates a true increase in the metabolic processes.

The fact that the carbon-dioxide exhalation is increased at a different rate from that of the oxygen consumption leads naturally to the supposition that the respiratory quotient, that is, the ratio between the carbon dioxide exhaled and the oxygen absorbed, is different during the periods of mental work from what it is during the periods of repose. In most of our experiments there was a tendency for the respiratory quotient to increase slightly during the mental work. The interpretation of this increase may be two-fold. One can argue that there is a change in the type of material burned and that mental effort calls for a somewhat larger proportion of carbohydrate. This would be in line with the present theories with regard to the exclusive combustion of carbohydrate during severe muscular work. Such a conclusion is by no means justified, for we have here to do with very considerable changes in the mechanics of respiration. Hence, the seeming increase in the respiratory quotient may well be merely an expression of the differences in the amount of air passing through the lungs or an indication of the washing-out of carbon dioxide.

Our conclusion in general, therefore, is that with intense, sustained mental effort, such as in multiplication, there is a noticeable increase in the heart rate, a rather considerable change in the character of the respiratory movements, an increase in the volume of air passing through the lungs, a small increase in the carbon-dioxide production, a smaller increase in the oxygen consumption, and consequently a slight increase in the apparent respiratory quotient. The increase in oxygen consumption, which may be taken as the best index of energy transformations, is such as to suggest that the increase in heat production as a result of intense mental effort of this type can hardly be of the order of more than 3 or 4 per cent. In view of the sense of extreme, almost overpowering fatigue in both mind and body following sustained mental effort, it is surprising that mental effort has such an insignificant effect upon the general metabolism or level of vital activity.