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THE EFFECT OF MENTAL ARITHMETIC ON CEREBRAL CIRCULATION AND METABOLISM [1]

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Considerable evidence exists to suggest that conscious mental activity is coupled to an active utilization of oxygen by the brain. When there is a deficiency in the oxygen supply to the brain, produced, for example, by anoxia or cerebral ischemia, consciousness is rapidly impaired (1, 2). Conversely, the depression of consciousness observed in various pathological states has been found to be accompanied by an appreciable reduction in cerebral oxygen consumption (3–6). Indeed, there has been observed a striking parallelism between the level of conscious activity in these states and the rate of oxygen utilization by the brain (7).

The fact that both cerebral oxygen consumption and conscious mental activity are concomitantly depressed in various non-physiologic states leaves unanswered, however, the question of whether the various mental activities which characterize the state of consciousness require energy derived from oxidative processes. It is conceivable that the oxygen required by the brain to sustain consciousness may be utilized only to maintain its structural and functional integrity without any oxygen being consumed by the actual mental processes themselves, in the sense that muscular work, either skeletal or cardiac, requires additional amounts of oxygen (8, 9). That such may be the case is suggested by the findings of Mangold and his associates that in natural sleep, a state of relative unconsciousness unassociated with pathologic processes, cerebral oxygen consumption is unchanged from the normal waking state (10).

Because of the nature of the phenomena, investigations of mental processes are limited almost exclusively to studies in unanesthetized man. A lack of suitable methods has prevented previous studies of the effects of mental activity on cerebral oxygen consumption. Attempts have been made, however, to describe, at least qualitatively, the effect of such activity on the cerebral circulation. Thus, Fulton has observed in a patient with an arteriovenous aneurysm overlying the occipital lobe that the bruit, audible through the occipital lobe, became more prominent when the patient was reading (11). In ten of fifteen cases, Lennox found increases in the oxygen content of internal jugular venous blood during the reading and performance of problems in mental arithmetic (12). He interpreted these results as indicative of a dilatation of cerebral vessels, reasoning that a decrease in oxygen consumption which would have produced the same findings was less probable.

The present availability of more specific methods permits a more definitive examination of the influence of mental activity on the cerebral circulation and metabolism, the purpose for which this study was undertaken.

METHOD

Studies of the effect of concentrated mental effort on cerebral circulation and metabolism were performed on 13 healthy, young, male university students and faculty members. Seven of the subjects were rested at the time of the study. The remaining six had originally been scheduled for similar studies in natural sleep (10) and had missed four to six hours of sleep; they were used in the present experiments because they were unable to sleep under the conditions of the procedure. Each study consisted of two determinations of cerebral blood flow by means of the nitrous oxide technique (13), first, a control determination during which the subject was in a state of complete physical rest and as great a degree of mental relaxation as the procedure would permit, followed by an experimental determination, during which the subject was presented orally with problems in arithmetic to solve mentally. To allow for a possible

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lag in the effect of mental exercise on the functions measured, the reading of the arithmetical problems was begun five minutes prior to the cerebral blood flow determination and continued throughout the ten-minute period required for the procedure. Since the face mask required by the nitrous oxide technique precluded vocal answers by the subjects, the problems were so designed that the answers were always an integer from one to five which could be indicated on the fingers of one hand. The problems were of sufficient complexity, however, to prevent solution without concentrated mental effort (Figure 1). Each answer, right or wrong, was immediately followed by a new problem. To minimize untoward emotional responses, the subjects were not informed of the correctness of their answers. Simultaneous electroencephalographic recordings from six to eight scalp electrodes were made throughout the study in six of the experiments in order to obtain independent evidence of mental concentration attending the solution of the arithmetical problems.

Mean arterial blood pressure was measured by means of a damped mercury manometer connected to the femoral arterial needle. Blood oxygen and carbon dioxide contents were determined by the manometric technique of Van Slyke and Neill (14). Arterial hemoglobin concentration was measured in the Evelyn photoelectric colorimeter according to a modification of the method of Evelyn and Malloy (15). Blood pH was measured anerobically at room temperature in a Cambridge pH meter and was corrected to 37° C. by means of the factors of Rosenthal (16). Cerebral oxygen consumption, cerebral vascular resistance, and cerebral respiratory quotient were calculated as previously described (13). Blood carbon dioxide tension was computed by means of the nomograms of Peters and Van Slyke (17).

$$38 + 19 - 1 \div 7 - 5 = 3$$

$$\sqrt{26 \times 2 \div 4 + 3} = 4$$

$$\sqrt{86 - 23 + 1} - 7 = 1$$

$$\sqrt{2^3 + 4^2 \div 6} = 2$$

$$11 \times 2 + 20 \div 7 \div 2 = 3$$

$$\frac{\sqrt{16} \times 5}{10} = 2$$

$$3^2 + 15 \div 8 = 3$$

$$\frac{55}{11} \times \frac{3}{\sqrt{9}} = 5$$

FIG. 1. SAMPLE PROBLEMS USED IN MENTAL ARITHMETIC STUDY

RESULTS

The data are presented in Tables I and II. Included for comparison are the mean values obtained by the same investigators in a series of control determinations in 11 normal young men and in a series of two consecutive control determinations in 13 "fatigued" individuals (10). The two consecutive control measurements were made under identical conditions but were separated in time by an interval approximating that between the control and experimental determinations in the studies on mental arithmetic (88 and 63 minutes, respectively). Although the subjects in the consecutive control studies were "fatigued" (*e.g.,* had remained awake four to six hours past their usual bedtime at the time of the study), these studies were considered adequate controls for the mental arithmetic studies for two reasons: 1) Six of the 13 subjects used in the studies on mental arithmetic were similarly "fatigued"; 2) no significant differences were found between "fatigued" subjects and normal rested young men (10). In one rested subject (J. Fo.), data on cerebral blood flow, oxygen consumption, and vascular resistance during mental arithmetic are lacking because of technical difficulties in the blood nitrous oxide analyses; the results of the other pertinent measurements which were successfully accomplished are included, however.

The performance of mental arithmetic was accompanied by statistically significant rises in mean arterial blood pressure (MABP) and pulse rate from the control levels (MABP: from 86 to 93 mm. Hg, $p < 0.01$; pulse rate: from 73 to 78 beats per minute, $p < 0.02$). These changes may be related to the moderate degree of apprehension which, at least, according to our subjective observations, many of these subjects exhibited concerning the display of their arithmetical ability. Despite repeated assurances that we were not keeping score, they reacted as though they were taking an examination, and some apologized in advance for any poor showing they might make. Indeed, one subject (E. L.) blocked completely and was unable to answer even the simplest problem. The results in this study were, therefore, ex-

TABLE I

Cerebral blood flow and metabolism during mental arithmetic

Subject	Age	Pulse rate		MABP mm. Hg		CBF cc./100 g./min.		CMR_{O_2} cc./100 g./min.		$(A\text{-}V)_{O_2}$ Vol. %		CVR mm. Hg / cc./100 g./min.		Cerebral R.Q.	
		C	E	C	E	C	E	C	E	C	E	C	E	C	E
Mental arithmetic—13 cases															
J. Fr.†	26	82	96	87	86	76	67	4.2	4.0	5.69	6.05	1.2	1.3	0.94	0.87
S. D.†	22	67	79	99	119	60	43	4.4	3.8	7.24	8.76	1.7	2.8	0.96	0.95
S. K.†	34	67	69	98	108	57	60	3.7	3.6	6.45	5.99	1.7	1.8	0.96	0.95
P. K.†	22	72	85	83	92	62	75	3.4	3.9	5.59	5.23	1.3	1.2	0.95	1.17
R. K.†	22	80	84	87	83	75	71	3.9	3.7	5.23	5.11	1.1	1.2	0.92	1.00
J. Fi.	26	74	73	85	83	73	63	4.2	4.3	5.78	6.76	1.2	1.3	1.05	0.93
C. P.	23	72	68	80	88	103	87	4.9	4.2	4.76	4.82	0.8	1.0	0.96	0.97
I. D.	21	78	76	80	87	64	68	3.7	4.3	5.77	6.34	1.3	1.3	0.98	1.03
F. K.	20	68	78	82	88	58	63	3.8	4.2	6.45	6.63	1.4	1.4	0.99	1.02
J. Fo.	20	68	66	86	94	64	—	3.7	—	5.79	6.25	1.3	—	0.90	0.99
J. A.	24	84	93	86	90	84	81	4.0	4.0	4.80	5.00	1.0	1.1	0.97	0.96
C. S.	24	66	74	83	92	54	57	3.7	4.0	6.78	6.98	1.5	1.6	1.10	0.96
E. L.*†	29	78	78	84	90	57	49	3.2	3.0	5.60	6.19	1.5	1.9	0.98	0.94
Mean	23.7	73.2	78.4	86.3	92.5	69.2	66.8	3.97	4.00	5.86	6.16	1.29	1.45	0.97	0.98
Stand. Error	±1.1	±1.9	±2.8	±1.8	±3.1	±4.0	±3.6	±0.12	±0.07	±0.22	±0.32	±0.08	±0.15	±0.02	±0.02
p‡		<0.02		<0.01		>0.3		>0.9		<0.1 >0.05		<0.2 >0.1		>0.7	
Consecutive control determinations in 13 fatigued subjects															
		I	II	I	II	I	II	I	II	I	II	I	II	I	II
Mean	23.6	71.0	72.7	90.2	96.0	64.8	60.0	3.65	3.52	5.85	6.02	1.46	1.68	0.93	1.02
Stand. Error	±0.9	±2.1	±2.7	±2.5	±2.1	±5.3	±3.8	±0.21	±0.16	±0.34	±0.29	±0.12	±0.12	±0.03	±0.02
p‡		>0.3		<0.01		>0.1		>0.4		>0.5		~0.01		<0.05	
Normal young men—11 cases															
Mean	21.8	69.3		86.5		54.8		3.34		6.25		1.68		0.92	
Stand. Error	±0.6	±2.6		±1.7		±4.3		±0.23		±0.40		±0.13		±0.03	
p§	>0.1	>0.2		>0.9		<0.05		<0.05		>0.3		<0.02		>0.1	

* Not included in statistical analysis because of complete mental block during mental arithmetic.
† Indicates "fatigued" subjects in mental arithmetic series.
‡ Represents significance of change between two determinations as calculated by method of paired comparisons.
§ Represents significance of difference between normal young men and control values in mental arithmetic series.

TABLE II

Blood constituents during mental arithmetic

Subject	Hb concentrations Grams %		O_2 content Vol. % Arterial		O_2 content Vol. % Int. jugular		CO_2 content Vol. % Arterial		CO_2 content Vol. % Int. jugular		pH Arterial		pH Int. jugular		CO_2 tension mm. Hg Arterial		CO_2 tension mm. Hg Int. jugular	
	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E	C	E
Mental arithmetic—13 cases																		
J. Fr.†	12.4	12.5	17.00	17.33	11.31	11.28	48.29	47.40	53.61	52.65	7.41	7.38	7.34	7.37	39	42	50	48
S. D.†	13.9	14.2	19.10	20.10	11.86	11.34	42.67	42.39	49.60	50.71	7.35	7.39	7.32	7.32	40	37	49	51
S. K.†	13.7	13.5	18.86	18.90	12.41	12.91	44.96	45.73	51.15	51.39	7.31	7.36	7.27	7.30	45	42	56	53
P. K.†	13.9	13.9	18.80	18.82	13.21	13.59	52.28	51.51	57.57	57.65	—	—	—	—	—	—	—	—
R. K.†	14.3	14.2	19.61	19.53	14.38	14.22	47.75	48.67	52.58	53.79	—	—	—	—	—	—	—	—
J. Fi.	15.0	—	19.65	19.80	13.87	13.04	50.30	49.52	56.39	55.83	7.39	7.40	7.32	7.32	44	42	57	56
C. P.	14.2	—	17.66	17.93	12.90	13.11	54.06	53.53	58.61	58.20	7.40	7.38	7.35	7.32	46	46	54	48
I. D.	13.6	—	18.11	18.44	12.34	12.10	51.69	50.97	57.32	57.54	7.39	7.35	7.35	7.31	45	47	53	57
F. K.	14.5	—	19.20	19.43	12.75	12.80	47.20	47.62	53.60	54.40	7.37	7.38	7.32	7.32	43	42	53	54
J. Fo.	15.0	—	19.78	19.93	13.99	13.68	48.17	47.52	53.39	53.68	7.34	7.33	7.29	7.29	47	47	57	58
J. A.	16.1	—	18.90	19.07	14.10	14.07	50.37	48.17	55.03	53.96	7.38	7.42	7.36	7.36	46	40	52	50
C. S.	16.1	—	20.23	20.51	13.36	13.53	49.53	50.12	57.10	56.84	7.41	7.42	7.38	7.38	41	42	51	50
E. L.*†	16.4	16.4	20.20	20.69	14.60	14.50	44.56	44.93	50.06	50.77	—	—	—	—	—	—	—	—
Mean	14.4	13.7	18.91	19.15	13.04	12.97	48.94	48.60	54.66	54.72	7.38	7.38	7.33	7.33	43.6	42.7	53.2	53.5
Stand. Error	±0.3	±0.3	±0.27	±0.27	±0.28	±0.28	±0.91	±0.84	±0.81	±0.72	±0.01	±0.01	±0.01	±0.01	±0.9	±1.0	±0.9	±1.2
p‡	>0.5		<0.02		>0.5		>0.2		>0.7		>0.5		>0.8		>0.9		>0.7	
Consecutive control determinations in 13 fatigued subjects																		
	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Mean	14.0	14.1	19.25	19.37	13.46	13.28	48.37	48.07	54.21	54.14	7.41	7.39	7.36	7.34	40.9	41.7	49.5	51.0
Stand. Error	±0.3	±0.3	±0.37	±0.32	±0.27	±0.27	±0.59	±0.51	±0.56	±0.46	±0.01	±0.01	±0.01	±0.01	±1.2	±0.8	±1.3	±0.9
p§	>0.1		>0.3		>0.5		>0.3		>0.8		~0.2		<0.1>0.05		>0.3		<0.05	
Normal young men—11 cases																		
Mean	14.6		19.44		13.20		47.45		53.11		7.39		7.34		41.3		51.6	
Stand. Error	±0.5		±0.49		±0.53		±0.73		±0.60		±0.01		±0.01		±0.9		±1.3	
p§	>0.7		>0.3		>0.7		>0.2		>0.1		>0.3		>0.5		<0.1>0.05		>0.3	

* Not included in statistical analysis because of complete mental block during mental arithmetic.
† Indicates "fatigued" subjects in mental arithmetic series.
‡ Represents significance of change between 2 determinations as calculated by method of paired comparisons.
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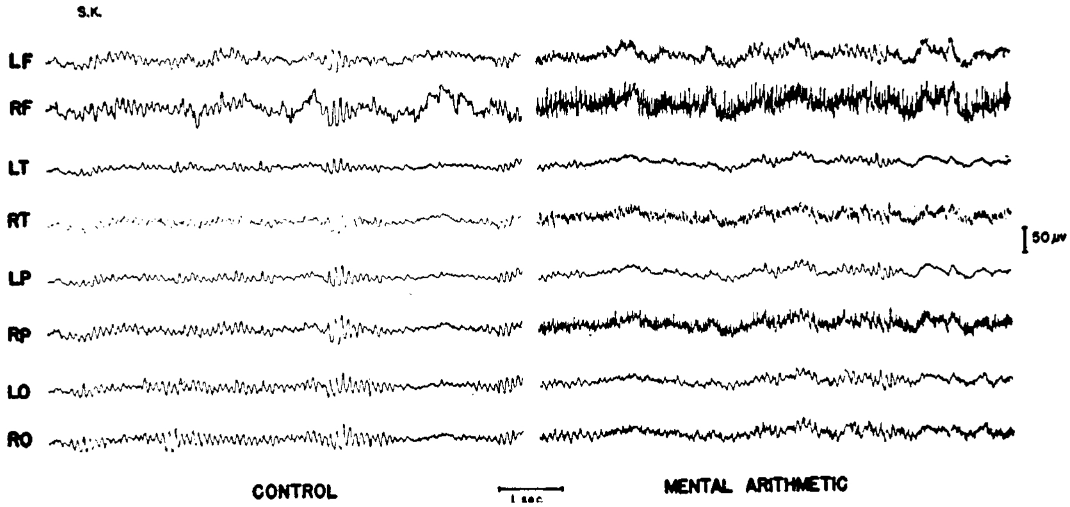

FIG. 2. EFFECT OF MENTAL ARITHMETIC ON ELECTROENCEPHALOGRAPHIC PATTERN

cluded from the statistical analysis. The blood pressure rise during mental arithmetic was not significantly different ($p > 0.9$), however, from a comparable rise in the consecutive control determinations, from 90 to 96 mm. Hg ($p < 0.01$) (Table I). There was no apparent anxiety or apprehension in the latter group to explain this rise, but there were frequent complaints of restlessness and discomfort from lying in one position for so long a period of time. No such complaints were heard in the mental arithmetic studies, perhaps, because of a preoccupation with the arithmetical problems. Unlike the results in the subjects performing mental arithmetic, no significant change in pulse rate occurred in the consecutive controls.

Despite the rise in MABP, cerebral blood flow (CBF) did not change from the control level during mental arithmetic (Table I). The rise in cerebral vascular resistance (CVR) which accompanied these changes was small, however, and lacked statistical significance. A slightly greater but statistically significant increase in CVR was observed in the second of the consecutive control determinations, the mean value being 1.7 mm. Hg per cc. per 100 g. per min. compared to 1.5 mm. Hg per cc. per 100 g. per min. in the first determination ($p \sim 0.01$). Despite the mental effort and despite a shift in the electroencephalographic pattern to higher frequency, lower voltage rhythms during mental arithmetic (Figure 2), both the control and the experimental values for cerebral oxygen consumption (CMR_{O_2}) were identical. Nor was CMR_{O_2} altered significantly in the two consecutive control determinations. Cerebral respiratory quotient (R.Q.) was also unchanged during mental arithmetic although a statistically significant increase from 0.93 in the first to 1.02 in the second of the two consecutive control determinations occurred ($p < 0.05$).

Except for a rise in arterial oxygen content from the control level of 18.9 vol. per cent to 19.2 vol. per cent ($p < 0.02$), no significant changes were found in any of the blood constituents during mental arithmetic. Since no increase in hemoglobin concentration was observed in the five cases included in the statistical analysis in which complete data were obtained, it may be that a hyperventilation associated with the anxiety was responsible. This explanation is questionable, however, in view of the statistically insignificant decrease in arterial CO_2 tension.

A comparison between the control values in the mental arithmetic studies and the results in another control series of normal rested young men reveals some surprising differences. The mean cerebral blood flow, 69 cc. per 100 g. per min., in the control determinations of the mental arithmetic studies significantly exceeded the value, 55 cc. per 100 g. per min., in the independent control series ($p < 0.05$). This difference was associated with a correspondingly lower cerebral vascular resistance in the control period before mental arithmetic than in the independent control group (mean values, 1.3 and 1.7 mm. Hg per cc. per 100 g. per min., respectively; $p < 0.02$). It is possible that the greater arterial carbon dioxide tension (43.6 mm. Hg compared to 41.3 mm. Hg) of the mental arithmetic group was responsible for their lower cerebral vascular resistance and higher cerebral blood flow although this difference lacked statistical significance ($p < 0.1 > 0.05$). Also contributing, perhaps, to the high cerebral blood flow and low cerebral vascular resistance of the subjects in the mental arithmetic studies was their unusually high value for CMR_{O_2}, 4.0 cc. per 100 g. per min., compared to the 3.3 cc. per 100 g. per min. obtained in this independent group of normal rested young men, as well as in others (13).

Although similar tendencies for high values of CBF and CMR_{O_2} and low values of CVR were observed in the first of the consecutive control determinations in "fatigued" subjects, these values did not differ significantly from those in rested young men. Also, no significant differences were observed between the rested and the "fatigued" groups of subjects within the mental arithmetic series.

DISCUSSION

One of the most intriguing problems in all of neurophysiology is the nature of mental processes, such as thought and reason. Yet, insofar as physiological investigation is concerned, it remains, to a great extent, unexplored territory. In order to approach the problem, we have accepted the common, though by no means universal, notion that mental functions reside within the brain, and the brain represents the proper area for their investigation. Having thus resolved the question of site, we have attempted to determine whether the mental processes involved in the performance of mental arithmetic are of a type in which energy utilization or transformation occurs. A positive result that thought processes require the utilization of additional quantities of oxygen by the brain would have led to such a conclusion. In view of our negative results, however, the conclusions are far less obvious, and we must give careful consideration to a number of possible interpretations.

First of all, it must be pointed out that in the strict physical sense, the performance of a useful function is not synonymous with the performance of work. Generally, organs whose functional activities are correlated with their rates of oxygen utilization are performing readily recognizable work, energy for which is supplied from chemical processes. Thus, skeletal and cardiac muscle perform mechanical work, and oxygen consumption increases with that work. Although Lennox considered the performance of mental arithmetic as "mental work" (12), it is not immediately apparent what the nature of that work in the physical sense might be if, indeed, there be any. If no work or energy transformation is involved in the process of thought, then it is not surprising that cerebral oxygen consumption is unaltered during mental arithmetic. The energy derived from the normal utilization of oxygen by the brain may then serve only to maintain its structural and functional integrity, and none is utilized by the actual thought process itself. The reduction in cerebral oxygen consumption in pathological states of reduced consciousness (7) may then reflect only a block in the maintenance mechanisms, and consciousness is reduced secondarily because of the failure to maintain structural and functional integrity. When there is no interference with the maintenance mechanisms, mental activity may be reduced, as in natural sleep (10), or increased as in mental arithmetic, without any change in cerebral oxygen utilization.

On the other hand, it is impossible to exclude unequivocally the possibility that mental activity consists of energy-dependent processes. Several other reasonable hypotheses which include this possibility can satisfactorily explain our results in mental arithmetic and sleep (10). First, the total energy requirements of the brain, as reflected by the cerebral oxygen consumption, may be independent of mental activity, but biochemical changes associated with that activity may alter the efficiency with which that energy is transformed to a useful form. Since all engines, including biochemical systems, are much less than 100 per cent efficient, considerable variations in energy output can be achieved in this way without altering the total energy supply. Secondly, in view of the complexity of the brain and the existence of inverse relationships between many of its component parts, mental activity or sleep may be accompanied by a redistribution in the patterns of activity throughout it. Areas with increased functional and metabolic activity could then be counter-balanced by areas of reduced activity so that the total cerebral oxygen consumption is unchanged. Finally, we are unaware of any estimate of the fraction of the total brain tissue which consists of functional units or neurones and are even less cognizant of the fraction of the neurones involved in the various functions which comprise conscious mental activity. The oxygen consumption of this fraction of the brain may be so small even under conditions of maximal activity, that we are unable to detect changes in it by means of a relatively crude method for measuring total cerebral oxygen consumption.

Some question may be raised concerning the validity of our controls for the study of mental arithmetic. Since it is impossible for a conscious human being to maintain his mind in a state of complete rest or inactivity, is it reasonable to assume a lesser degree of mental activity in the control determinations than during the performance of mental arithmetic? Evidence to support such an assumption is provided by the electroencephalographic recordings made simultaneously with the determinations in six of the studies. During the control periods a typical resting EEG pattern was generally obtained, but during the mental arithmetic, there was, despite the frequent presence of muscle artifact, a clear and obvious shift to low voltage, high frequency, asynchronous rhythms (Figure 2), a change frequently associated with conditions of presumably increased cerebral activity (18). It appears then that neither the degree of mental activity nor the electroencephalographic pattern are correlated with the total cerebral oxygen consumption.

Our results fail to confirm the rise in internal jugular oxygen content observed by Lennox during mental arithmetic or the elevation of cerebral blood flow which he postulated on the basis of that rise (12). We are unable to account for the discrepancy in results, but in view of the dependence of the internal jugular venous oxygen content on other factors which he did not measure, such as arterial oxygen content and cerebral oxygen consumption, it can scarcely be considered a reliable indicator of cerebral blood flow.

Several unexpected observations in the course of these studies seem to offer information relative to the still controversial question of whether anxiety alters cerebral circulation and metabolism (7, 19). In order to explain the findings of substantially higher control values for cerebral blood flow and oxygen consumption in the mental arithmetic group than in an independent group of controls, the possible influence of anxiety cannot be disregarded. These two series of studies were performed under similar conditions by the same group of workers employing identical methods, and the two groups of subjects chosen at random from the same pool of volunteers. Furthermore, the two series were conducted simultaneously so that individual studies were more or less randomly distributed between them. It is true that five of the mental arithmetic subjects included in the statistics had missed several hours of sleep prior to the study, but a large group of similarly "fatigued" subjects have shown no significant differences from the independent group of normal controls (10). Also within the mental arithmetic series there were no recognizable differences between the "fatigued" and rested subjects. The only immediately apparent difference between the subjects employed in the mental arithmetic studies and the normal controls was in the degree of anxiety exhibited. The subjects in the mental arithmetic studies evidenced considerable apprehension about the showing they would make in solving the problems, not only during the experimental period, but even during the preparations for the study before the control determination. In the absence of any other apparent factor, anxiety must be suspected as a possible cause of the elevated cerebral blood flow and metabolic rate in this group of subjects.

SUMMARY

1. Studies of cerebral circulation and metabolism at rest and during the mental exertion required in solving problems in arithmetic were made in 13 young university students and faculty members.

2. Despite a shift in the electroencephalographic pattern to lower voltage, higher frequency, asynchronous activities and small but statistically significant rises in pulse rate and mean arterial blood pressure, no changes in cerebral blood flow, cerebral oxygen consumption, cerebral vascular resistance, and cerebral R.Q. from the control levels were observed during the performance of mental arithmetic.

3. Except for a slight increase in arterial oxygen content, mental arithmetic was not accompanied by any changes in blood constituents such as oxygen and carbon dioxide concentrations, carbon dioxide tension, pH, or arterial hemoglobin concentration.

4. Comparison between the subjects in the mental arithmetic study and an independent group of normal controls reveals significantly higher values for cerebral blood flow and oxygen consumption and a lower value for cerebral vascular resistance in the mental arithmetic subjects, even during the control determinations. The only immediately apparent difference between the two series which might account for these changes was the obvious anxiety exhibited by the mental arithmetic subjects at exhibiting their arithmetical ability.

5. These findings demonstrate a lack of correlation between both the degree of mental activity and the electroencephalographic pattern and the rate of oxygen consumption of the brain as a whole.

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