MENTAL PERFORMANCE AND THE ACID BASE BALANCE OF THE BLOOD IN NORMAL INDIVIDUALS[1]

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Introduction. The problem consists in the determination of the relationship between variations in mental performance and variations in the acid-base balance of the blood in the same individual over a period of time. The influence of acid-base balance of the blood on feelings of well being as reported subjectively by the individual is also considered.

Previous studies on physiological changes and physiological conditions of mental work may be grouped into two main categories:

(a) Physiological changes concomitant with mental work, and,

(b) Physiological conditions influencing mental work.

Most of the studies of physiological conditions influencing mental performance deal specifically with the effects of certain drugs, such as alcohol, tobacco, strychnine, etc. Darrow (1) has reviewed this literature recently

One phase of this problem of comparatively recent development is the work of German investigators on the effects of recresal administration on mental efficiency.

Emden (2) showed that the addition of recresal, (mono sodium hydrogen phosphate) to the diet would increase physical and mental efficiency noticeably. The work was carried out on horses and men.

Poppelreuter (3) has recently reported lengthy experiments in which evidence of increased mental efficiency as measured by speed and accuracy of working arithmetic problems is found in all five of the subjects tested with the administration of recresal. The improvement in speed was from 7 percent to 20 percent, while in accuracy the improvement was greater, from 20 percent to 40 percent. Although all details of the experiments were not given, they seem well controlled.

Strauch (4) in a clinical discussion, claims improvement of backward children in school by daily administration of small dosages of recresal, although no experimental data are given.

Greisbach, (5) in another clinical article, offers evidence from clinical practice for the beneficial effects obtained from the administration of recresal orally as a stimulant.

While Sullivan (6) was able to demonstrate a slight relationship between mood and weather conditions, no correlations could be found between mood and mental performance or weather and mental performance.

Bethel (7), in a study of the relationship between weather conditions and mental performance, obtained inconclusive results, since three cases showed little or no relationship between efficiency of immediate recall and humidity, whereas one showed direct variation between the two, and two showed perfect inverse variation. Relative humidity, barometric pressure, and temperature appear to affect the efficiency of auditory memory. The investigator feels that barometric pressure is the most important factor, a low pressure being favorable to mental work.

Proc. Ind. Acad. Sci. 40: 193-202. (1930) 1931.

[1]Part of a thesis submitted at the University of Chicago in partial fulfillment of the requirements for the Degree of Doctor of Philosophy.

Lawson (8), in a study of the effect of oxygen deprivation on mental work, concluded that cumulative patterns failed while habitual associative connections remained intact, or nearly so, even under conditions of relatively low oxygen tensions.

Bagby (9), in a similarly titled study, carried out by means of a re-breathing apparatus producing progressive asphyxia, found a reduction in ability to carry on a number of discrete tasks simultaneously through rapid shifting of attention. he also found a constant but irregular decrease in steadiness during the preliminary stages of the asphyxia.

Abramovitch and Pichugina (10) report that physical fatigue caused by weight lifting and running diminishes the durability of the associative reflex.

On the other hand, Kantorovitch (11) studied the effect of mental fatigue on a previously established associative reflex. Fatigue was produced by complicated arithmetic work. A comparison study was made on physical fatigue induced by dynamometer squeezing. The latter had no effect on the associative reflex. Thus it seems that while local physical fatigue has no effect on the associative reflex, more or less general physical fatigue exerts a disturbing influence.

While attempts have been made to measure changes in the blood during and after periods of mental work, no studies on the problem of the effect of blood condition on the efficiency of mental work have been reported.

The present study is an attack on the problem of the effect of blood condition on the efficiency or rate of mental performance. While various blood constituents might be studied, the acid base balance was chosen for the following reasons: (1) its close association with both the respiratory and excretory functions of the individual, (2) the relative tenacity with which the acid-base system resists displacement, (3) the fact that this system is worked out more completely in physico-chemical terms from the researches of Van Slyke, Henderson, and their co-workers, than any other blood system, and, (4) the feasability of the development of a micro method of determination.

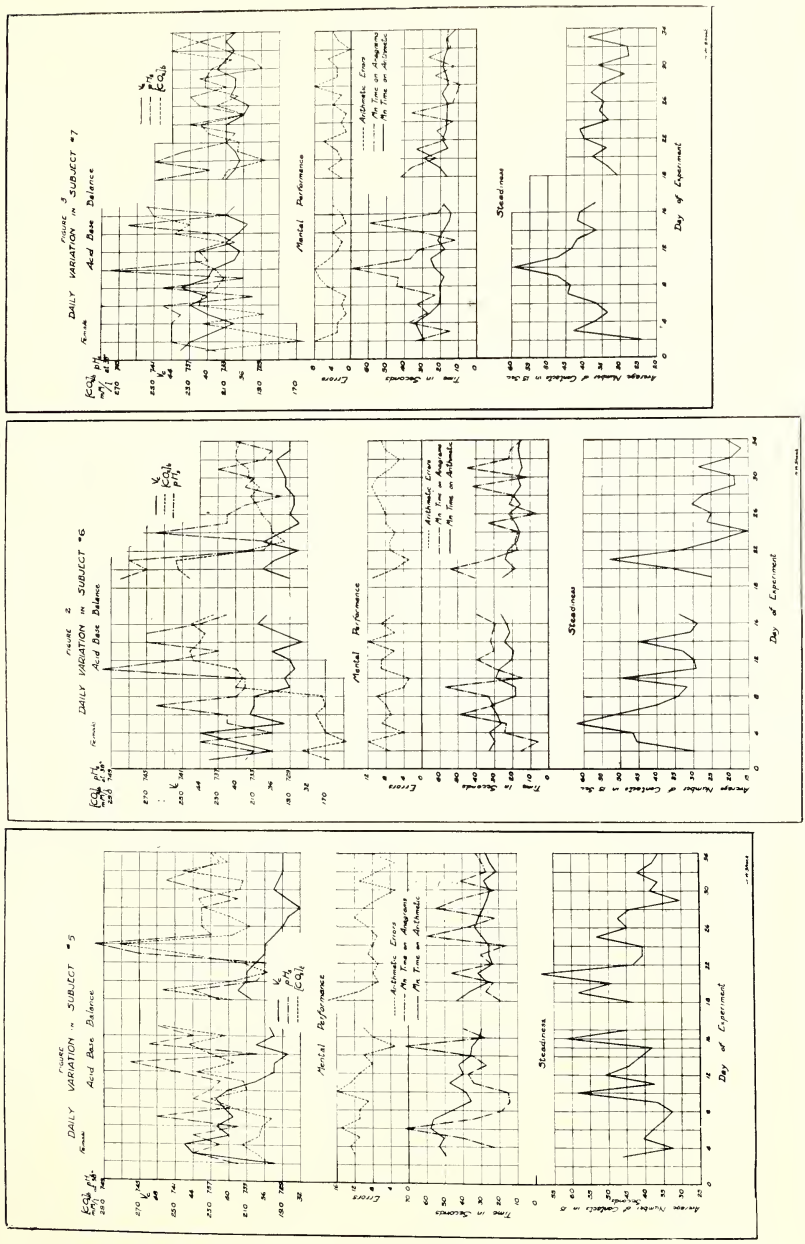
Experimental Methods. As tests of mental performance the following were used:

(1) Mental multiplication. Each test was made up of ten problems of mental multiplication of two place by two place numbers. The problems were presented on 3x5 cards, the subjects carrying out the operations mentally and recording the complete answer on a typewriter electrically connected with a time recording device that gave the time required on each problem to the nearest second.

(2) Anagram test. Each test was made up of ten anagrams constructed by disarranging the letters of five letter words, all chosen from the first 5,000 words of most wide and frequent occurrence, according to Thorndike. (12) (Such as: llawo, cslsa, etrla, etc.) The subject again wrote the response on the typewriter, which gave the time required for each anagram. The score consisted of the mean time required per anagram.

In addition a steadiness test was used in which the subject, while standing, held a stylus 1 mm. in diameter within a hole 3 mm. in diameter attempting to keep from touching the side of the hole for fifteen seconds. The score consisted in the average number of contacts per fifteen seconds in four trials.

Ratings. A series of graphic rating scales was constructed to aid in obtaining introspections as to the feelings of the individual which might in some measure be treated quantitatively. The subject placed a check on a line to indicate his feelings



Figs. 1, 2, 3—Time curves showing daily records of subjects in cell volume (Vc), pH of serum (pHs), total carbon dioxide content of whole blood $(CO_2)_b$, arithmetic errors, mean time on anagrams, mean time on arithmetic problems, and average number of contacts of the stylus in fifteen seconds.

at the time in regard to (1) physical power, (2) capacity for mental work, (3) exhaltation or depression, and (4) degree of sleepiness.

Since existing methods of analysis of the blood required about 10 cc. samples, a micro analytical technique was developed by which the percentage cells, the pH of the serum and the total CO_2 content can be determined on a sample of 0.1 cc. of blood drawn from a finger prick. (13) From these data the carbonic acid content of the blood, the CO_2 tension, and the bicarbonate content of the serum were calculated by means of a nomogram devised for the purpose.

Experimental. The study was carried out on seven female and eight male subjects, who came to the laboratory without breakfast at the same hour of the day six days a week for thirty days. The order of administration of tests was: (1) Fill out rating scales, (2) work arithmetic tests, (3) work anagram test, (4) steadiness test, and, (5) take blood sample.

Results. The results of the tests and analyses were plotted as a function of time,—figures 1 to 3 being characteristic samples. From these graphs it can be seen that daily fluctuations in both blood condition and mental performance are large within given individuals. It is also evident that the amount of fluctuation is different in different individuals. In the case of the blood measures, the fluctuations do not show reversals in direction each day, but show general periods of rise and fall continuing over several days. Subject Number 5, fig. 1, a female, shows such periods quite noticeably, although no constancy of periodicity can be demonstrated from the present data. Such periods of continuous rise or fall do not occur on the same dates for different individuals, thus indicating that they are not the result of some factor common to all subjects, such as weather conditions, or the analytical technique.

As a further check on the question of whether fluctuations observed in the acid-base balance of the blood are the results of the experimental technique, the blood data were averaged by days, and a group curve for each blood measure plotted. It was found that although this average curve did show variations from day to day, all the fluctuations except two of the thirty were within one standard error of the mean, which indicates that they were not of significance and could be attributed to chance.

Table I is a summary of the data gathered arranged to show individual differences, giving the mean and standard deviation of the distribution for percentage cells, (V_c), pH of the serum, total CO_2 content, steadiness, arithmetic and anagram scores for each of the subjects. Statistical tests of significance show that in all measures there are significant individual differences, although not all individuals vary significantly from one another. From these data the conclusion seems justified that by sufficient sampling it would be possible to obtain an average value which might characterize the blood of a given individual as to acid base balance, although single observations may be quite valueless for such a characterization.

From the individual time curves the following points seem evident:

(1) In some subjects periods of several days of successive rise or fall in any of the blood measures may be observed. See Fig. 1.

(2) The percentage of red cells is higher in the men than in the women, as would be expected from differential blood count data.

(3) Variation in blood condition and in mental performance differs for different individuals, those showing great fluctuation in mental performance

TABLE I

INDIVIDUAL DIFFERENCES

MEANS AND STANDARD DEVIATIONS OF ALL SUBJECTS IN ALL MEASURES

Subject	V_c		pH_s at 38° C		$[CO_2]_b$ [1]		pCO_2 [2]		$[BHCO_3]_s$ [1]		Steadiness [3]		Arithmetic [4]		Anagrams [4]	
	Mn	σDist.	Mn	σDist.	Mn	σDist.	Mn	σDist.	Mn	σDist.	Mn	σDist.	Mn	σDist.	Mn	σDist.
1	.402	.0313	7.358	.095	20.42	1.15	42.40	4.39	23.17	2.01	6.88	4.51	21.80	9.17	19.20	6.33
2	.389	.0251	7.386	.099	21.94	2.61	42.19	4.97	24.80	1.94	12.54	4.27	38.83	7.90	30.88	16.66
3	.450	.0297	7.366	.056	22.02	1.03	45.83	5.84	25.24	1.46	6.44	3.49	34.54	8.64	29.89	11.71
4	.434	.0244	7.341	.065	21.70	1.21	47.33	4.93	24.89	1.53	28.58	6.91	18.04	3.70	20.58	12.05
5	.369	.0313	7.381	.070	22.31	1.85	43.26	3.25	24.94	2.08	42.26	11.38	35.69	10.10	33.18	13.60
6	.357	.0268	7.377	.059	21.06	2.59	40.84	5.35	23.34	3.04	32.61	11.64	21.73	5.47	28.23	12.87
7	.382	.0212	7.358	.078	21.75	2.05	44.22	5.69	24.10	1.94	37.65	6.87	19.07	4.02	27.53	14.02
8	.464	.0184	7.404	.044	21.14	0.63	40.93	3.30	24.88	0.93	16.42	4.71	13.26	1.96	.....	.....
9	.465	.0153	7.342	.071	22.01	1.12	48.52	4.70	25.51	1.46	8.84	3.98	33.85	6.32	55.28	22.53
10	.374	.0142	7.362	.046	22.01	1.06	44.43	3.92	24.44	1.34	43.35	7.15	30.52	8.83	31.77	17.12
11	.472	.0187	7.346	.047	21.70	1.11	47.48	4.89	25.21	1.49	27.36	5.52	22.88	5.43	26.72	11.72
12	.461	.0157	7.365	.054	22.22	0.86	46.60	5.21	25.81	1.05	9.05	5.28	21.46	6.47	22.00	10.14
13	.472	.0178	7.326	.028	22.22	1.09	50.92	4.71	25.80	1.17	25.01	7.45	35.70	9.62	70.42	26.69
14	.507	.0171	7.345	.030	22.25	1.24	49.55	4.82	26.31	2.73	6.20	3.44	21.39	5.54	35.94	16.37
15	.451	.0182	7.372	.052	21.86	1.27	45.00	5.51	25.30	1.57	37.01	8.83	57.23	11.74	27.15	15.35
16	.386	.0128	7.395	.046	23.80	1.67	45.32	5.72	26.57	1.02	22.91	11.29	20.10	5.37	32.71	16.36

1. Milli mols per liter.
2. Millimeters of Hg.
3. Contacts per 15 seconds.
4. Time in seconds per problem.

tending to show greater variation in blood condition, and those showing a relative constancy in mental performance tending to be more constant in blood condition.

(4) Learning is a factor in the psychological tests which varies considerably from individual to individual in its effect.

Acid base balance charts were prepared for each subject by plotting pH against the bicarbonate content of the serum. In these charts the course of the variation in acid base balance from day to day was followed, but no regularity seemed evident between different individuals.

Acid base balance and mental performance. A search was made for possible correlation between blood condition and mental performance. Due to the wide individual differences in scores on the mental tests, such correlations were sought within the records for each individual.

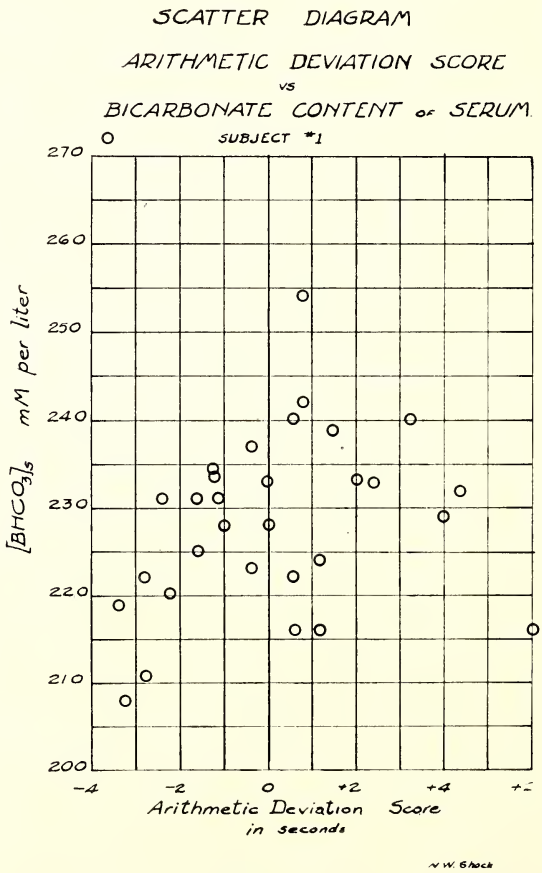


Fig. 4

Fig. 4—Correlation scatter diagram showing relation between the arithmetic deviation score and the bicarbonate content of the serum in subject Number 1. Each point represents one day of experiment

Reference to the time curves (Figs. 1-3) shows practice effects extending over the course of the experiment in all the psychological tests, especially so in the mental arithmetic. Practice seems negligible in the case of the anagram records for most subjects—at least no intelligible learning curves could be drawn through the points. The same was true of the steadiness records, although some subjects did show decided practice effects. Free hand learning curves were fitted to the daily arithmetic scores and deviations from these curves were used as daily arithmetic scores in the correlational work. If the experimental value obtained on a given day was above the curve it was given a plus sign, if below, a minus. Hence plus scores indicate that the subject took longer on the test on that day than would be expected on the basis of his learning.

In order to test for the presence of a correlation between the two variables under consideration, values for one were plotted against values for the other on the same day. Some 225 such scatter diagrams were plotted to test for the presence of correlation between any of the blood measures (both experimental and calculated), and any of the psychological measures. Figure 4 is a sample plot showing arithmetic deviation score plotted against the bicarbonate content of the serum for subject number 1. This is one of the better diagrams most showing much less correlation. On the basis of these plots, it seems that no significant correlations can be demonstrated from these data between mental performance and acid base balance of the blood.

In such an attempt to measure differences in mental efficiency it is necessary to assume equal difficulty of the tests given from day to day. Tests were selected with as much care as possible to make them of equal difficulty. That differences in difficulty actually existed between the tests appears evident on examination

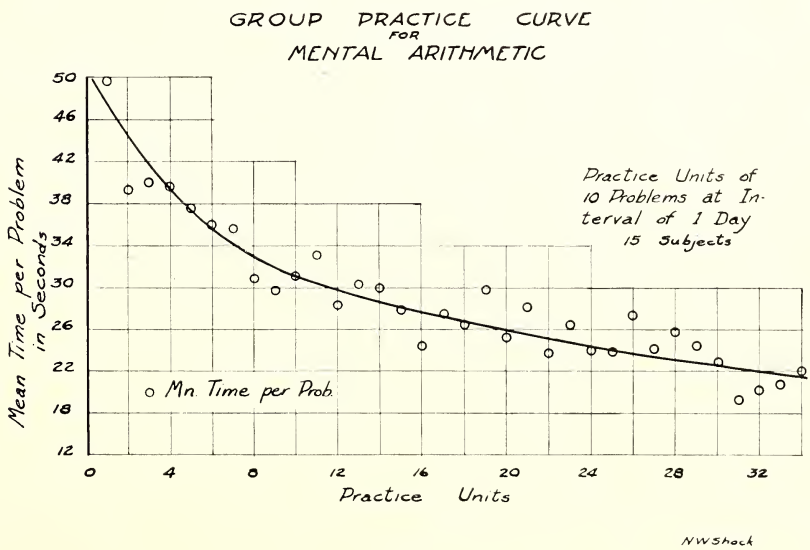


Fig. 5

Fig. 5—Group practice curve for mental arithmetic. The mean time per problem in seconds is plotted against practice units of ten problems. Variation of the points around the curve may be due to differences in difficulty of the sets.

of the group learning curves for arithmetic and anagram tests, although the arithmetic tests seem to be more nearly equal in difficulty than the anagram tests. Figure 5 shows the group practice curve for arithmetic problems. These group curves show fluctuations in the averages from day to day which seem to be due to differences in difficulty of the tests. Just how much this difference in difficulty of the tests influences the results remains an open question. However, it is possible that, although some relationship actually exists between mental efficiency and acid base balance of the blood, the correlation between the measures taken in this experiment might be zero because of the adverse influence of the tests used.

Blood condition and feeling tone. From the rating scale data, the days on which a given subject reported feelings of well being as represented by high ratings, as well as the days on which he reported average and bad feelings were separately tabulated. From this tabulation the means of the various blood measures on days on which the same rating was given were calculated. In subjects who usually reported average feelings with little deviation, no differentiation could be made. However, in the case of those subjects making careful ratings, and who showed considerable variation in feelings throughout the course of the experiment, slightly positive results could be demonstrated in the case of the bicarbonate content of the serum. The differences between the means of the different groups were not statistically significant, since the number of cases in each category was relatively small.

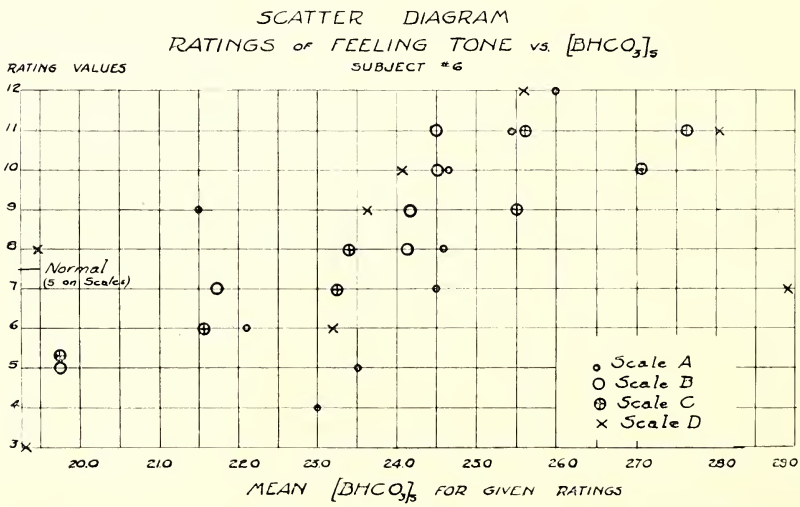


Fig. 6

Fig. 6—Correlation scatter diagram showing relation between subjective ratings of feeling tone and the bicarbonate content of the serum of subject number 6.

A sample chart is shown in figure 6 for subject number 6. Rating scale value is plotted against bicarbonate content of the serum, which shows a slightly positive relationship; that is, the subject tended to report feelings of well being on days

when the bicarbonate content of the serum was higher. This same relationship was observed in all the other five subjects making sufficiently fine differentiations in their ratings. The fact that all four rating scales show the same relationship seems to indicate that the subjects actually rated the same thing on all four scales.

The results of such experiments are of course limited by the usual shortcomings of rating scales, but it seems that at present there is no other way of attacking the problem of subjective states in any manner that approaches quantitativeness.

Conclusions.

1. There are wide fluctuations from day to day in the acid base balance of the blood of a given individual.

2. These fluctuations are much greater in the case of some individuals than in that of others.

3. There are diurnal fluctuations in the acid base balance of the blood of a given individual, although no definite rhythm seems apparent.

4. There are significant individual differences between the acid base condition of the blood of different persons.

5. No correlation can be demonstrated between acid base balance of the blood and mental performance as measured by the tests used in this study.

6. No correlation can be demonstrated between acid base balance of the blood and steadiness as measured by the test used here.

7. There is a slight tendency for some persons to report feelings of well being on days when the acid base balance of the blood tends toward the alkaline side.

Discussion. The lack of decisive positive findings in this experiment does not seem to be proof that there is no relationship between blood chemistry and either mental performance or feeling tone.

In the first place, it may well be that the acid base balance of the blood is an ill advised mechanism to study in this connection. This may be true, since it is known that the acid base mechanism of the blood is a function of physico-chemcial laws that have been fairly well worked out and is so well suited to maintain its own balance and function that the relationships sought are too fine to be discerned by the crude techniques available on the psychological side.

There is also the factor of temporal relations. It was tacitly assumed in this investigation that blood condition and mental performance would show concomitant variation. However, it is possible that there is a time factor separating the two series; that is, the condition of the blood today may have little or no effect on the performance today, while it may have a great effect on performance twelve hours hence.

The most probable explanation for the negative findings here reported seems to me to be the fact that as yet no standard tests of mental efficiency are available which will give anything like the accuracy of estimate given by the refined chemical techniques available. Mental multiplication is scarcely to be compared with or treated as a test for capacity to do mental work.

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