A STUDY OF THE RELATIONS BETWEEN MENTAL ACTIVITY AND THE CIRCULATION OF THE BLOOD.

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The purpose of this investigation is threefold. The first problem concerns the changes in the rate and force of heart beat and the vasomotor fluctuations concomitant with agreeable and disagreeable sensations and affective states under conditions of mental acuity and fatigue. The second treats of these differences as connected with processes of intellection during the progression to a state of mental fatigue. The third is a consideration of the vasomotor rhythm, indicated by the Traube-Hering waves, in relation to the acuity of sense perception observed to recur in rhythmic regularity.

In consideration of the admirable historical review of observations relevant to the subject of this investigation made by J. R. Angell and H. B. Thompson,[1] a review of the literature would here be superfluous.[2] The results and conclusions of former investigators will be considered wherever it is desired to make statements of comparison.

I here take the opportunity to acknowledge my indebtedness to Dr. Edwin Grant Dexter, professor of education in the University of Illinois, under whose general direction this study has been made; to Dr. Stephen S. Colvin, assistant professor of psychology in the University of Illinois, and the several students who have acted as subjects for experimentation; and to Dr. John A. Bergström, of Indiana University, under whose di-

[1] PSYCH. REV., VI., pp. 32–43.

[2] Publications since the issue of the above study make possible the following additions: Wundt, *Philos. Studien*, XV., 140. Wundt, 'Völkerpsych., I., II., 1900, 40 ff. W. P. Lombard and W. B. Pillsbury, *Amer. Journ. of Physiol.*, III., 186–201. A. Lehmann, 'Die körperlichen Aeusserungen psychischer Zustände, I., Plethysmographische Untersuchungen,' Leipzig, 1899.

rection preliminary experiments on phases of the same problem were made, which furnished the inspiration for the present investigation.

Apparatus and Experiments.

A continuous kymograph, highly adjustable with respect to speed, designed and made in the laboratory of the department, was used for taking tracings. A chronograph indicated a seconds time tracing. Marey tambours, to which were attached inking cups and capillary pens drawn from glass tubing, were used to produce the tracings on white paper. For continuous records this method has many advantages over smoked paper tracings.

Both the time-rate of the pulse and the vasomotor changes in the peripheral blood vessels were recorded by the use of the

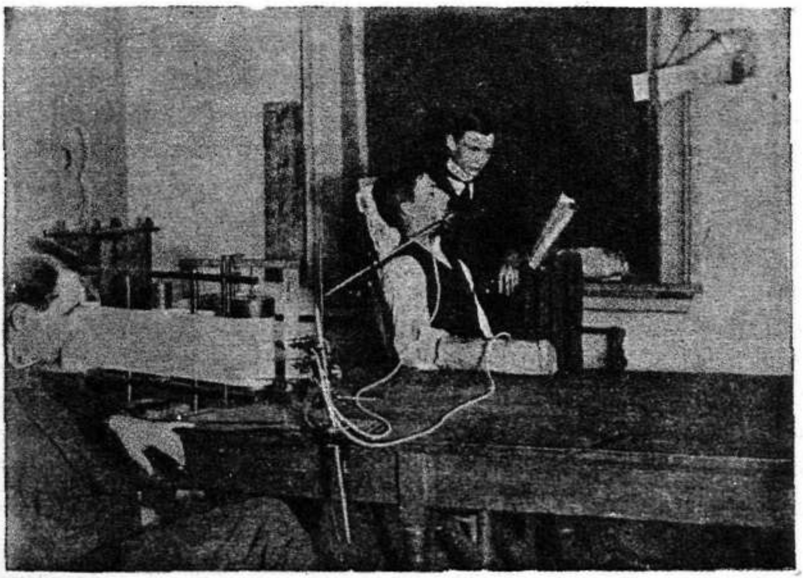

FIG. 1. Apparatus used in taking simultaneous sphygmographic and plethysmographic tracings.

plethysmographic tracings, save in a few cases where sphygmographic records were taken directly from the carotid. The air plethysmograph was used. Most of the records were taken from the forearm, but a few were from the foot. For the tests involving fluctuations of attention, a tambour giving the tracing was placed in connection with a press bulb. The stimulations used were visual and auditory. An audiometer was used for the latter as much more satisfactory than the ticking watch; for visual stimuli the Masson disc and geometrical figures were used. Extended experimentation was required before the most suitable speed of kymograph, the most desirable temperature of the room, the best quality of rubber, the proper manipulation of the pens and the most satisfactory position of the body were secured.

The series of records upon which this paper is based consists of the results of extended and complete tests taken from twelve subjects. For the long records the subject remained in the chair with the apparatus attached for from forty-five to sixty-five minutes. For the tests in responses to emotional states and brief intellectual application, the subject was taken at a time of mental acuity, before the prolonged task was begun and again after the completion of the hour's vigorous work.

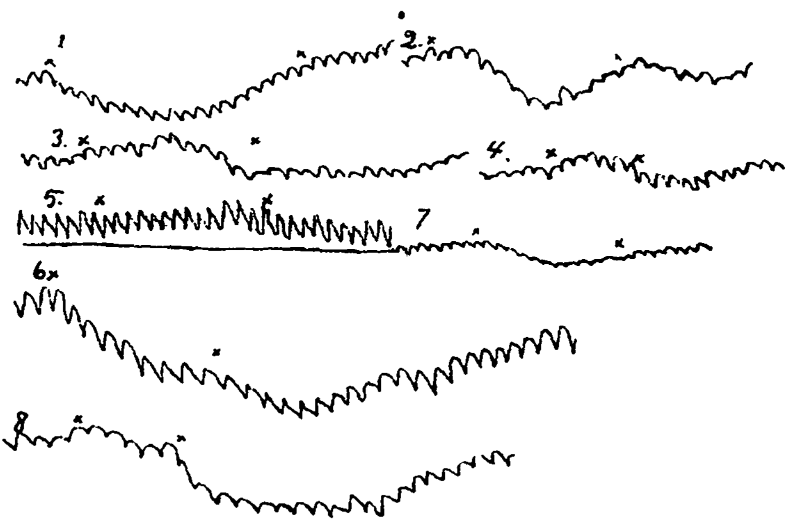

FIG. 2. Curves 1, 2, 3, heliotrope; 4, 5, crab apple; 6, 7, 8, carbon bisulphide.

Explanation of Figures. All curves read from left to right. The application of a stimulus or the solution of a problem begins at the point marked with a cross, terminating at the second cross. A drop in the curve indicates vasoconstriction; a rise, vasodilation.

Many records were taken from the twelve subjects, and also from others, which were not used. Wherever, through any error in adjustment or working of technique, question arose as to the validity of tracings, they were thrown out. Careful tests have assured me that the accuracy of the curves used may be fully relied upon as indicating changes in the rate and volume of the blood flow to the parts used in the experiment and to show the character and amplitude of the capillary pulse.

I. Affective States.

The emotional states here considered were all produced by agreeable or disagreeable odors. Curves 1 to 5 are tracings of agreeable odors; 6 to 10, of disagreeable. All these are plethysmographic except 5 and the upper curve of 9. In these the rate of heart beat during the emotion varies with the vasomotor changes of the peripheral blood vessels. Vasodilation is accompanied by an accelerated heart rate and vasoconstriction by a diminished rate. In every case constriction occurs, although constriction is preceded by dilation in curves 2, 3, 4, 11 and 13. This is most marked in 3, taken from B., and in 9 and 13, from D., these subjects invariably showing this effect, regardless of the character of the emotion. In subject B., constriction was never very evident, either in emotional or intellectual activity.

It has been held by Féré[1] that agreeable experiences are accompanied by dilations of the capillary blood vessels and disagreeable experiences by constrictions. Alfred Lehmann[2] agrees with this, and Wundt[3] has embodied Lehmann's conclusions in his *Völkerpsychologie*. No other investigators have found any foundation for these conclusions. I find that all emotional experiences are accompanied by constriction, either immediately or after brief dilation. For most individuals, normal vasomotor recovery is more rapid after an agreeable experience than after a disagreeable feeling. Compare curves 1 and 6.

It may be noted that the vasomotor activity of the peripheral vessels precedes, in some cases, the constriction or dilation of

[1] 'Sensation et mouvement,' Paris, 1887.

[2] 'Hauptgesetze d. mensch. Gefühlslebens,' tr. by Bendixen, Leipzig, 1892.

[3] 'Völkerpsychologie,' i, I., 1900, 40, ff.

the carotid. (See curves 9 and 18.) This suggests the question of control of the blood supply to the brain, a question as yet having received no completely satisfactory solution. The view of Mosso[4] that the blood supply to the brain is a condition and not a cause of psychic activity finds support in these curves.

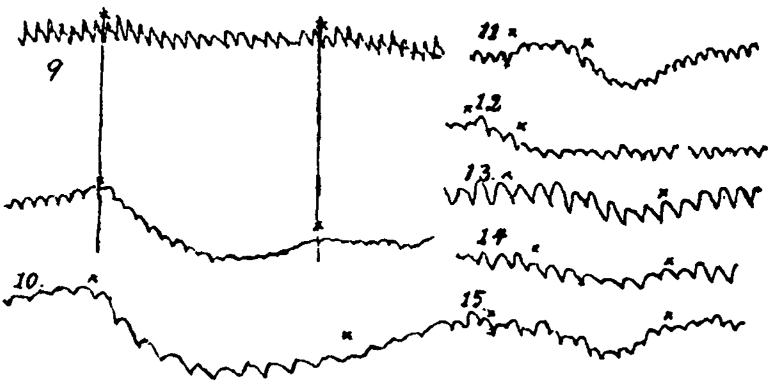

FIG. 3. Curves 9, 10, carbon bisulphide; 11, 13, carbon bisulphide before work; 12, 14, 15, same after one hour's work. Upper curve in 9, from carotid.

This question will be discussed further in the last section of the paper.

Curves 11, 12, 13, 14, 2 and 15 show the effects of fatigue upon the circulatory responses to emotional states. Curves 12, 14 and 15 are tracings for the application of the same stimuli as in curves 11, 13 and 2 respectively, after one hour's rigorous mental activity. The effects of fatigue are shown in the greatly diminished amplitude of pulsations, the diminished heart rate, the diminution in vasomotor response to stimulation, and the greater retardation in the recovery of the vasomotor level.

II. Intellectual Activity.

The tests employed in these experiments for intellectual activity were mathematical problems for the short periods, and memorizing or reading difficult subject matter for the prolonged records. Curves 16 to 21 are plethysmographic tracings for problems in addition and multiplication. In every one of these vasodilation precedes constriction, and in all the heart rate in-

[4] 'Die Ermüdung,' p. 195, ff.

creases during the period of vasodilation. In all excepting 16 the amplitude of the pulse curve is diminished. Curves 19 and 20 were taken from subjects M. and B. respectively, whose records for almost every test given of any kind failed to show any marked constriction, where it was shown being preceded by dilation. This was especially true of B., further shown in curves 27 and 28. It is to be noted, however, that the amplitude of the pulse curve is greatly reduced and the heart rate is quickened, indicating an increased blood pressure.

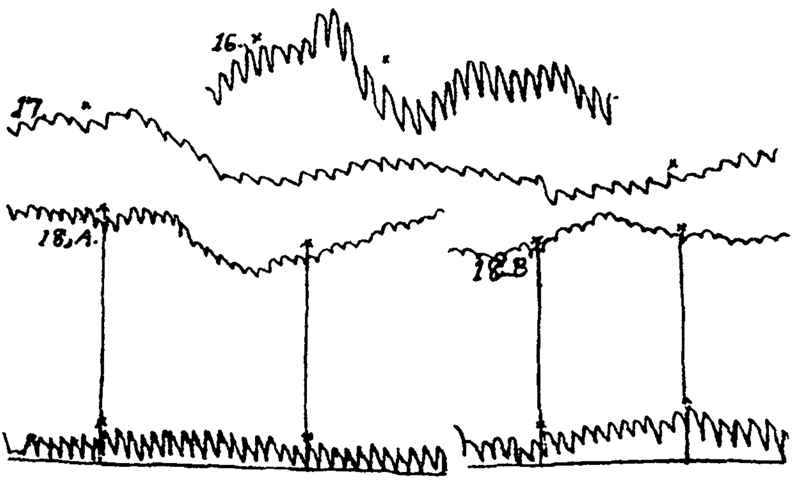

FIG. 4. Curve 16, addition; 17, multiplication; 18, both A. and B., addition; in 18, lower curve from carotid.

Curves 22 to 24 are from the carotid. So also are the lower curves in curves 18, A. and B. All these excepting 23 show vasodilation and all of them show diminished amplitude of pulse curve, indicating an increased flow of blood under a greater arterial pressure. Curves 22 and 24 also show clearly that the dicrotism of the carotid pulse is much less acute. The dicrotic notch is almost obliterated during intellectual activity in curve 22. These results are quite the opposite of those of Gley[1] who found that mental work increases the amplitude of the carotid pulse and accentuates the dicrotic notch. Binet and

[1] 'Etude expérimentale sur l'état du pouls,' etc. Paris, 1881.

Henri[1] agree with the results here given in finding an increased blood pressure during intellectual activity.

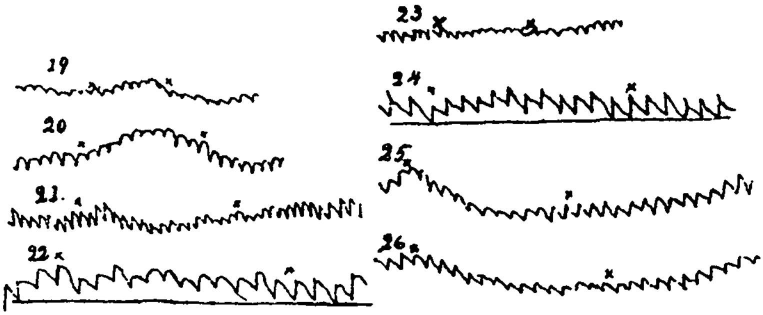

FIG. 5. Curves 19, 20, 21, multiplication; 22, 23, addition, from carotide; 24, multiplication, from carotid; 25, addition, before work; 26, same, after one hour's work.

The tracings for intellectual activity given by Angell and Thompson[2] show far less vasomotor response than do the ac-

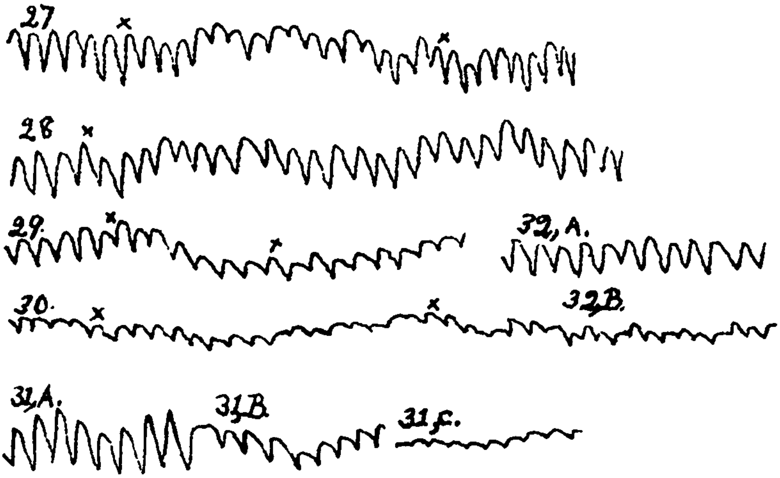

FIG. 6. Curves 27, 29, multiplication, before work; 28, 25, same, after one hour's work; 31, A., before work; B., in fortieth minute; C., in sixtieth minute; 32, A., before work; B., in sixtieth minute.

companying curves. They also point out a regularity and stability in the circulatory processes concomitant with intellec-

[1] 'La fatigue intellectuelle,' pp. 112, 113.

[2] *Ibid.*, pp. 61, 63, 64.

tual activity much greater than that observed for emotional activity.[1] The accompanying curves fail to show any such differentiation. These differences in observations emphasize the fact that there are great individual differences in subjects. The equivocal character of the literature on this subject may be very largely due to the individual variations, no previous investigator having employed a sufficient number of subjects to realize the necessity for caution in generalizing.

Curves 25 to 30 show the effects of fatigue on the circulation in its responses to intellectual activity. Curves 25, 27 and 29 represent short mathematical problems before work was begun by the subjects. Curves 26, 28 and 30 indicate problems of the same degree of difficulty by the same respective subjects after one hour's rigorous mental application. The subjects remained in the chair during the hour with the apparatus attached, a continuous tracing being recorded. In no cases are records here compared which were taken at different sittings. Not only are differences in physical and mental states in the subject so great as not to admit of comparison, but it is not believed that adjustments of apparatus are possible which will insure tracings susceptible of valid comparison as to absolute dimensions. In these three sets of tracings, fatigue is evident in the greater time required for the solution, in the diminished rate of heart beat, in the diminished amplitude of the pulse curve and in the reduced vasomotor response to the intellectual stimulus.

Curves 31, 32 and 33 are plethysmograms, and 34 and 35 are sphygmograms showing the progress of fatigue. Curve 31, A., at the beginning of work, B., in the fortieth minute and C., in the sixtieth minute, indicate the diminished heart rate and pulse amplitude through one hour's continuous work. Curve 31, A., before work, B., in the tenth minute, C., in the twenty-fifth minute and D., in the fortieth minute, show both the diminished pulse rate and amplitude, and the changes in the dicrotic notch through forty minutes of close mental application. Curves 34 and 35 show these diminutions in rate and amplitude, and more clearly the changes in the dicrotism of the pulse through forty minutes rigorous mental work. Fig. 7 indicates clearly the

[1] *Ibid.*, p. 67.

effects of fatigue on both the capillary pulse and the carotid, curves 34 and 35 each being carotid tracings, while 33 is from the forearm. The loss of acuteness in the dicrotic notch is

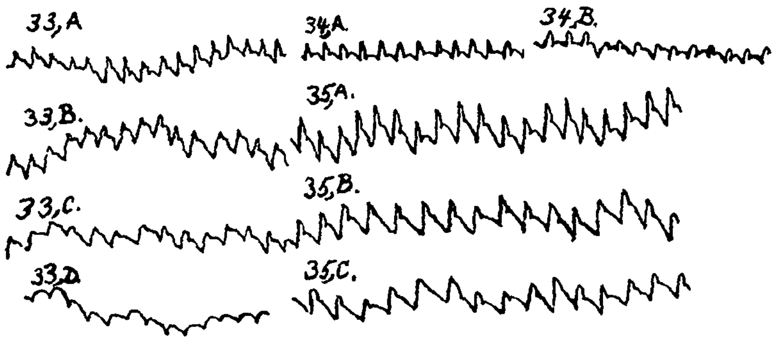

FIG. 7. Curve 33, A., before work; B., in the tenth minute; C., in the twenty-fifth minute; D., in the fortieth minute; 34, A., before work; B., in the fortieth minute; 35, A., before work; B., twenty-fifth minute; C., fortieth minute; 34, 35, from carotid.

plainly evident in both, but the anacrotic effects are most fully developed in the capillary tracings.

Figs. 8 to 11 give reduced records of plethysmographic tracings, showing both the heart rate and the vasomotor fluctuations through periods of from forty minutes to sixty-five minutes. The records show conditions at intervals of one minute. In these figures the numbers at the top and bottom of each line indicate in minutes the progress of the experiment. In every case the upper record in each figure is based upon the rate of heart beat. The lower record indicates the vasomotor fluctuations. The numerals at the right and left of the pulse-rate curves express the number of beats of the heart each minute; those at the right and left of the vasomotor record show the height of the curve in the tracing in millimeters.

Binet and Courtier[1] are the only observers who have made similar tests for long periods of time. Their experiments were with two subjects and covered periods of five hours. Tests were taken at intervals of about one hour, the apparatus being removed after the test and the subject retiring to an adjoining

[1] 'La fatigue intellectuelle,' p. 97.

room. The validity of the comparison of records taken under such circumstances is open to question. In continuous records the fluctuations vary from two to twenty millimeters in vasomotor level. Short tracings taken at intervals of an hour might show either extreme of these variations. The movements to the

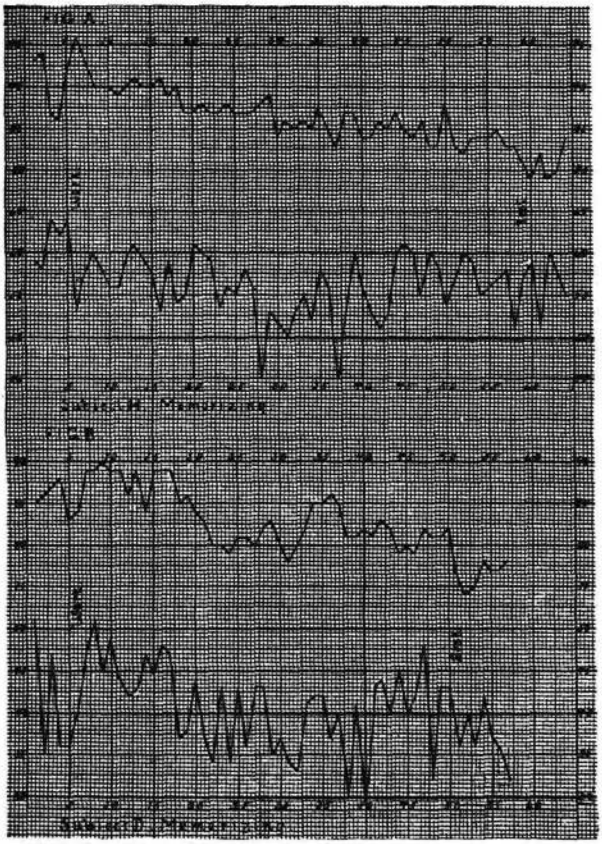

FIG. 8. Prolonged intellectual application. Upper curve in each figure for heart rate, lower for vasomotor changes. Numerals at top and bottom of each figure indicate minutes of progress; at the right and left of the upper record the heart rate per minute, of the lower record the height of the tracing in millimeters.

room and for the adjustment of the apparatus, together with the mental relaxation occasioned by these movements, would introduce possibilities of additional error, all of which are obviated by the continuous records. As to the rate of heart beat, two types of records are found. Those shown in Figs. 8, 9, and curve E, of Fig. 10, indicate the one form in which the rate progressively diminishes under intellectual activity, or diminishes for a considerable time, then remains approximately the same for the remainder of the hour. Fig. 8 shows the former

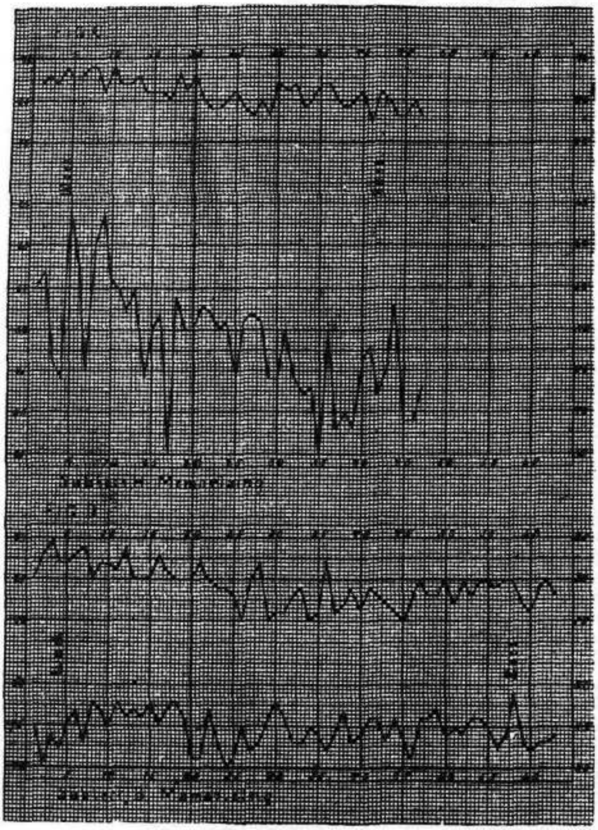

FIG. 9. Prolonged intellectual activity. For explanation see FIG. 8.

condition, curve D, of Fig. 9, the latter. The second type is shown in curve F, of Fig. 10, and in Fig. 11. Here also two forms occur, curve F illustrating the first, a general rise in the rate until the close of the hour. Fig. 11 shows the other form, in which there is an increased rate for a considerable period then a diminution.

In curves A and B, the fall is steady, after the short rise at the beginning, from 94 beats a minute to 80 in the former and from 89 to 76 in the latter. In curve D, Fig. 9, the rate drops from 82 to 75, then at the forty-sixth minute rises and remains

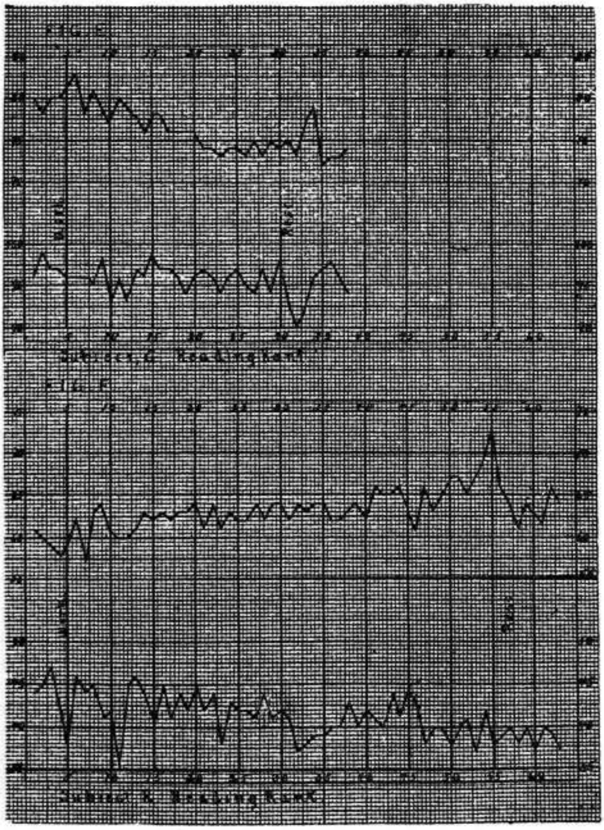

FIG. 10. Prolonged intellectual activity. For explanation see FIG. 8.

at or near 80. In curve F, Fig. 10, the rate rises from 58 to 65, takes a sudden rise to 73 in the fifty-fifth minute, then falls back to 63 at the close of the hour. Curve H, Fig. 11, shows a rise from 81 to 86 by the thirty-fifth minute, then a fall to 81 again by the end of the hour.

The fluctuations in the vasomotor records are much greater than those in the rate of heart beat. The records in Fig. 8 and curve C, of Fig. 9, indicate a type in which the vaso-constriction increases until about the fortieth minute, then slightly diminishes for the remainder of the period. Curve D, Fig. 9,

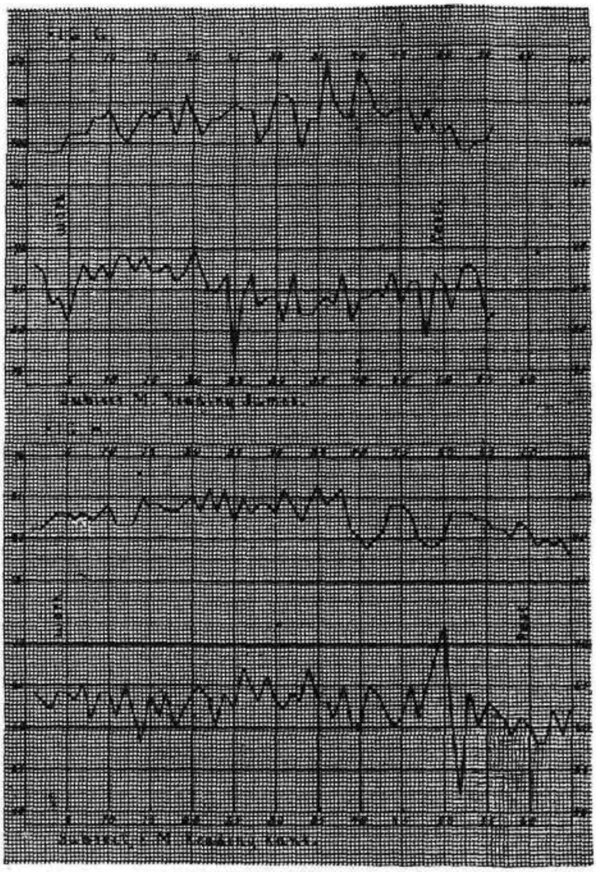

FIG. 11. Prolonged intellectual activity. For explanation see FIG. 8.

and curve H, Fig. 11, show the type in which there is no progressive vasomotor activity. In curve D, after a slight dilation, constriction bringing the curve down to the resting level follows, and slight fluctuations in both directions recur at intervals of from two to four minutes through the hour. In curve H, there is a gradual dilation up to the thirty-fourth minute, then a progressive constriction for the remainder of the period. In curve F, the constriction is continuous and progressive through the hour, the curve falling from a height of 44 millimeters to 37, as measured on the tracing.

Curves A, B and F show a tendency toward recovery in the increased heart rate, and curves A, C, G and H, in vasodilation, during the short period of rest recorded at the close of the intellectual labor. But recovery from such prolonged and intense application is too slow to be very markedly evident in the first few minutes of relaxation. Fluctuations in both the records for the pulse rate and for the vasomotor level are rhythmical, the periods varying from one to three minutes. There is also a correspondence observed between the two rhythms. In general, an increase in vasoconstriction for one or two minutes is followed by an increase in the rate of heart beat. This correspondence is confined to short periods of time, however, for most subjects. One record only is found where the parallelism is continuous and progressive through the long period, curve F, Fig. 10, showing this for fifty-five minutes

W. H. Howell[1] found that the blood pressure begins to diminish in a subject sitting for a sleep record as soon as he is comfortably seated, and continues to diminish for from an hour to an hour and one half.

Prolonged intellectual activity produces the opposite result. curves 31, 32 and 33 clearly indicate the progressive increase in blood pressure. How long it might continue to increase it is beyond the province of this investigation to state.

III. The Traube-Hering Rhythm and Fluctuations of Attention.

During periods of rest or after the subject had become absorbed in concentrated study, long undulations, covering the time of two or three respiration periods, appeared with great prominence and regularity in the tracings of a number of individuals. The time of these wave-lengths corresponds fully with the periods of the Traube-Hering blood pressure waves and the changes in amplitude of the parts of the wave indicate the blood pressure changes. Therefore the term Traube-Hering is be

[1] *Jour. of Exp. Medicine*, II., p. 319.

lieved to be valid as applied to these undulations and is used when they are referred to. Types of these waves from five

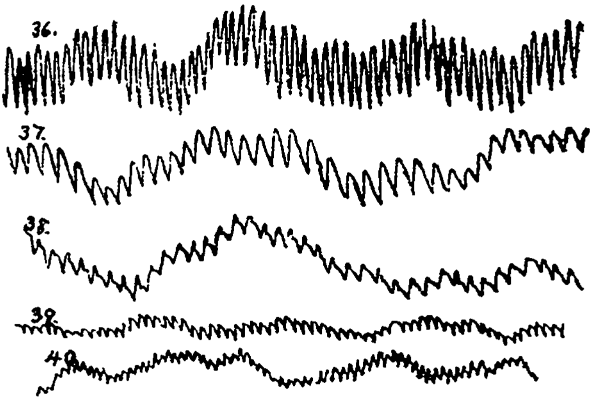

FIG. 12. Types of Traube-Hering Waves.

different subjects are shown in Fig. 12. The parallelism of the waves from the arm and foot is seen in Fig. 13.

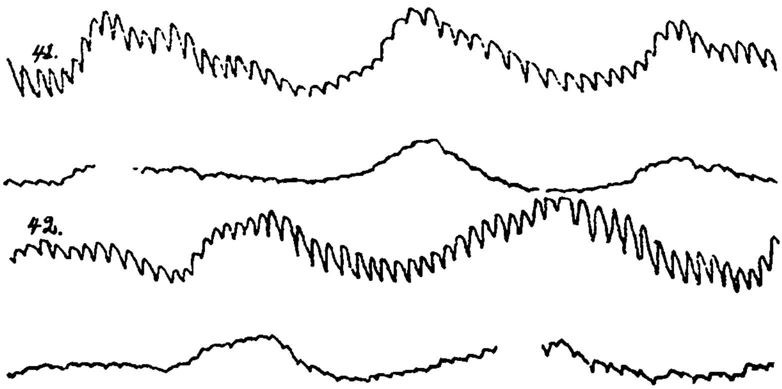

FIG. 13. Showing Parallelism of Arm and Foot Plethysmographic Tracings. Lower Tracing from the Foot.

The agreement of these wave lengths with the periods of rhythmic variations in the acuity of auditory and visual perception observed in the use of the Masson disc or the audiometer suggested that there might be a causal relation, or at least a constant correspondence between the two. Tests were made with the results shown in Figs. 14 and 15. Curve 43 is a tracing recording the appearances and disappearances of the

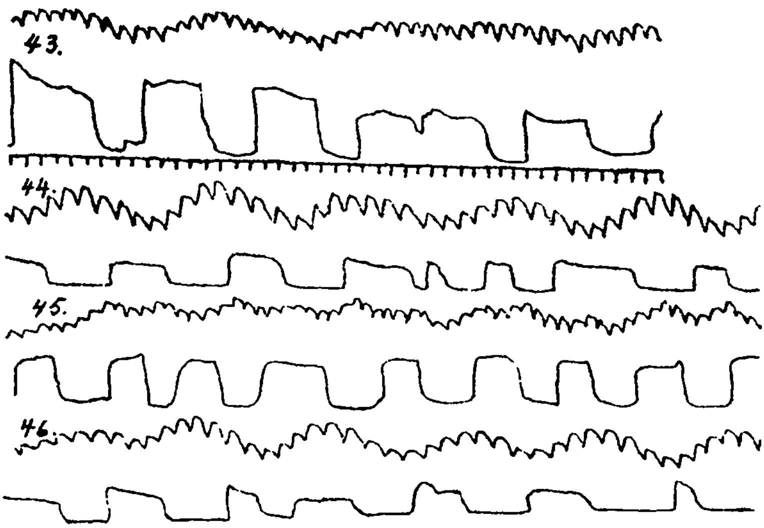

FIG. 14. Parallelism of Traube-Hering and Attention Waves. Curve 43, Masson Disc ; 44, 45, 46, geometrical figure.

gray ring in the Masson disc. Curves 44, 45 and 46 show the changing appearance of a pyramidal figure from convexity to concavity and *vice versa* by three different subjects, each con-

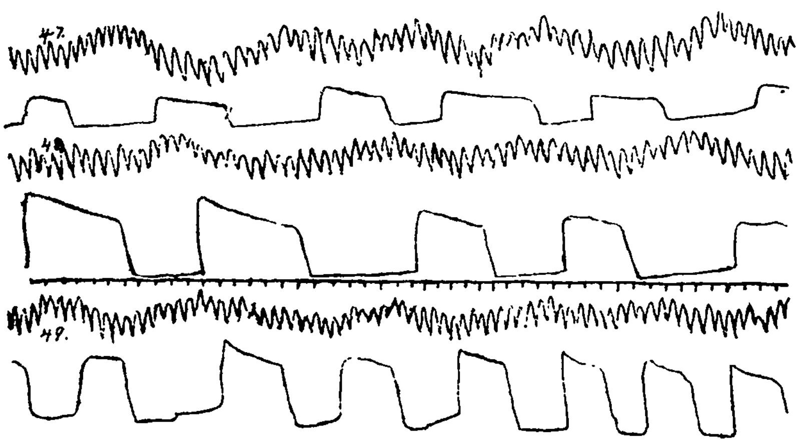

FIG. 15. Parallelism of Traube-Hering and Attention Waves. 47, Retinal-rivalry; 48, Audiometer ; 49, Masson disc.

sciously attending to the convex appearance. Curve 47 is a tracing for retinal rivalry, attention being directed to the image on the right eye. Curve 48 is a tracing for the appearances and disappearances of sound by use of the audiometer, and curve 49 a record from the use of the Masson disc. In all of these tracings the crests of the attention waves indicate the appearances of the sensation, the valleys the disappearances.

The possible relation of the rhythmic fluctuations in the intensity of sensations to the Traube-Hering waves was expressed by Roy and Sherrington[1] in 1890, but, hitherto, no experimental evidence has been offered to establish this relation. While the waves do not always fully coincide, in general there is a very close correspondence. The crests of the attention waves are usually coincident with the valleys of the Traube-Hering undulations. Using the audiometer set at the threshold of auditory perception, the minimal sound appears soon after the period of vasoconstriction; it increases until the maximum is reached just after the beginning of vasodilation and is lost near the middle of the curve's ascent.

The most recent and complete investigation of the causes of the Traube-Hering waves is that by Lombard and Pillsbury.[2] Their conclusion is that these waves are caused by a rhythmic activity of the vasomotor center. They found a quickening of the heart during vasoconstriction and a diminution during dilation. But the accompanying curves very markedly show the reverse of this. The quickening of the heart begins at the moment of vasodilation and continues almost to the crest of the wave, when a diminution begins and is maintained to the valley of the following wave. This agrees with the results of Binet and Courtier,[3] who made some observations on these waves in 1895. This also confirms a general observation which is exemplified in Figs. 2, 3, 4 and 5, namely, that when vasodilation precedes constriction, regardless of the mental state accompanying it, the rate of the heart is quickened until the beginning of constriction; and that when constriction is immedi

[1] *Journal of Physiol.*, XI., p. 108.
[2] *Am. Journ. of Physiol.*, III., pp. 201–228.
[3] 'L'année psychologique,' 1895, p. 124.

ately occasioned by a mental state, the pulse rate is diminished until the beginning of dilation. In curves 41 and 42 especially, and in 38 and 39, the diminished amplitude and reduced rate of the pulse are clearly evident during vasodilation. The same may be noted in curves 3, 9, 19, 20 and 24. Bayliss and Hill,[1] in a study of cerebral circulation and blood pressure, conclude that 'cerebral circulation passively follows the changes in the general circulation.' The above facts lend support to this view and to the conclusion that the circulation of the brain is controlled through the action of the vasomotor center acting upon the splanchnic area in governing the rate of heart beat and upon the vasomotor nerves controlling the peripheral circulation.

Why mental states should produce vasoconstriction in some subjects and vasodilation in others can not be answered in the light of present knowledge. In either case the fluctuation in the general circulation provides for an adequate blood supply to the brain—in vasodilation by an increased heart rate and a heightened blood pressure—in vasoconstriction by a diminished volume of blood to the periphery.

Summary of Results and Conclusions.

Both emotional states and intellectual activity are accompanied by change in heart rate and blood pressure in all individuals, and by vasomotor changes of the peripheral vessels in most persons.

In general, a quickened heart rate is concomitant with vasodilation, a slower rate with vasoconstriction.

The only constant variation observed in the tracings for agreeable, as distinguished from disagreeable experiences, is a tendency toward more rapid recovery to the vasomotor level in the former.

Intellectual fatigue is accompanied by a diminished vasomotor response to emotional states, and recovery is much slower than during mental acuity.

Prolonged intellectual activity produces a diminished amplitude of the pulse curve, an increased blood pressure and a diminution in the acuteness of the dicrotic notch. In most sub-

[1] *Journ. of Physiol.*, XVIII., p. 357.

jects a diminution of the heart rate occurs during the progress of an hour's mental activity, but in a few the rate is increased for this period.

In prolonged intellectual application, three types of vasomotor effects are noted: one of progressive constriction; one of no progressive vaso-changes, and one showing progressive constriction for a certain period then continuing at that level or showing slight vasodilation for the remainder of the hour.

A rhythm of from one- to three-minute periods is observed in both sphymographic and plethysmographic tracings. In general there is a tendency to coincidence in rhythm, a vasodilation being concomitant with an increased heart rate.

In most subjects during states of mental regularity and stability, as in repose or continuous intellectual application, the Traube-Hering waves are clearly defined in the tracings.

The pulse rate is quickened and the amplitude diminished during the period of vasodilation in the progress of the wave, the rate lowered and the amplitude increased during vasoconstriction.

These Traube-Hering undulations correspond in wave-length with the fluctuations of acuity in visual and auditory sense perception, the greatest acuity occurring just after the maximum of vasoconstriction.

The correspondence of vasomotor activity and heart rhythm, the response of the splanchnic and peripheral vasomotor activities to cerebral activity, and the evidence that the cerebral circulation is varied in consequence of changes in the systemic circulation, support the conclusion that the blood supply to the brain is controlled through the action of the vasomotor center. This is effected through irradiations to the splanchnic area which governs the rate of the heart beat and to the vasomotor nerves which control the peripheral blood flow.