STUDIES FROM THE HARVARD PSYCHOLOGICAL LABORATORY. (IV.)

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The Physical Characteristics of Attention.

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The researches here to be reported upon were concerned with the phenomena of functional disturbance which accompany various forms and degrees of perceptual and reflective attention.

The subject was seated in a comfortable position with body relaxed and eyes closed, beside a table upon which the instruments were placed. The conductor of the experiments, who gave the signals and applied the stimuli, stood at his back, by which arrangement undesired knowledge of the nature of the stimulus or other matter of technique was avoided.

Records were taken of the character of the breathing, of the changes in pulse form and blood supply in the left forearm and of the alterations in muscle tension in the fingers of the right hand.

Upon the subject's breast was fastened a Marey tambour pneumograph, held in position by tapes passing over the shoulders and around the body under the arms. To the stem of its bulb was attached a rubber tube connecting with the chamber of a pneumatic registering pen, whose point traced the curve of respiration upon the surface of a horizontally revolving drum covered with smoked paper. During the later experiments a second pneumograph was added which recorded the character of the diaphragmatic respiration.

The features of the pulse and of blood distribution were recorded in one composite tracing given by an air plethysmograph. This consisted of a glass cylinder fifty centimeters long and ten in diameter, open at one end and at the other drawn to a neck, in which a cork, having a glass tube passing through

it, was tightly fitted. Around the open end of the cylinder was stretched a rubber band twelve centimeters wide, which was cemented to the glass and formed an air-tight bandage upon the subject's arm when inserted in the cylinder. This cylinder was suspended by cords from the ceiling at such a height that the subject's arm, when inserted in it, might be in an easy position as he sat in the chair. This long radius from the point of support gave great flexibility in yielding to slight motor reactions on the part of the subject, those which normally occurred in the course of the experiment—as observation proved—having no appreciable effect upon the character of the pulse and volume curve. When the arm, as far as the elbow, had been placed in the glass chamber, the plethysmograph was connected by means of a rubber tube attached to that passing through the cork in its neck, with a registering pen similar to that used in recording the respiration.

The muscles selected for observation were those of the index finger of the right hand, which, during the early experiments, was placed in the holder of a Delabarre muscle recorder, and afterwards in an adaptation of this instrument, by which the direct extensile and contractile changes without the lateral movements were recorded. The right forearm rested upon a stand drawn up beside the subject, the wrist being supported by a cushion, the hand turned laterally, and the index finger, slightly flexed and free from interference or support by the others, inserted as far as the first joint in the muscle recorder.

The giving of the signals and the application of and relief from the various stimuli were recorded by the momentary deflections of a registering pen operated by pressure upon a rubber bulb held in the hand of the conductor of the experiment. There were thus traced upon the one drum at the same time five curves, two registering the respiration, a third the pulse and blood distribution, the fourth the muscle changes, and the fifth the giving of signals and application of the stimuli. The five points of the registering pens were aligned upon the face of the cylinder with each other and with the time recorder, so that being under the control of the operator, there was possible an exact knowledge of the correspondence between the phases of

application, relief, etc., and the changes of the function recorders. The smoked paper records were subsequently fixed by dipping in an alcoholic solution of gum sandarac. The tracings were read with the aid of triangles and millimeter scales by reference to base lines parallel to the direction of rotation of the drum. Full notes were taken of each experiment, its conditions and the experience of the subject during its course.

Functional Changes during Perceptual Attention.

The subject sat in an easy position, with eyes closed and instruments adjusted. A period of thirty seconds was allowed to elapse during which he remained quiet, avoiding all movement and mental effort. At the close of this period a watch was opened and brought forwards to the subject's ear, until it was just possible for him, with considerable effort, to follow its ticking. To this faint, rhythmical sound his close voluntary attention was given during a second period of thirty seconds; and a third of similar length, in which the effects of relief and the return of functioning towards the normal type could be observed, closed the experiment. Silence was maintained through the three periods. At the close of each experiment the subject described his mental experiences, the degree, constancy, and mechanism of his attention, disturbances, and the like, so that the quality of the subjective condition represented by the record was known in each case. The following figures exhibit the character of the respiration during perceptual attention.

Average Length of the Respiratory Phases.

1. Normal.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.68 secs.	.33 secs.	1.08 secs.	1.51 secs.
B	.75 "	.47 "	1.41 "	1.16 "
C	1.35 "	1.08 "	2.59 "	2.55 "
D	1.21 "	.11 "	1.08 "	1.93 "
E	.77 "	.24 "	1.03 "	1.34 "
F	1.31 "	.27 "	2.07 "	1.71 "
G	.95 "	.32 "	1.31 "	1.14

	Total Respiration.	Depth.		Total Resp.	Depth.
A	3.59 secs.	14 mm.	E	3.38 secs.	17 mm.
B	3.81 "	11 "	F	5.35 "	24 "
C	7.45 "	36 "	G	3.62 "	27 "
D	4.34 "	40 "			

2. During Attention.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.83 secs.	.87 secs.	1.45 secs.	1.25 secs.
B	.73 "	.39 "	1.38 "	.93 "
C	1.12 "	.45 "	2.70 "	1.08 "
D	.74 "	.11 "	1.08 "	1.38 "
E	.69 "	.36 "	1.42 "	1.76 "
F	1.34 "	.22 "	2.02 "	2.09 "
G	.69 "	.57 "	.94 "	1.05 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	4.41 secs.	.19 mm.	E	4.27 secs.	.24 mm.
B	3.43 "	.15 "	F	5.58 "	.22 "
C	5.81 "	.13 "	G	3.28 "	.15 "
D	3.31 "	.28 "			

The characteristic changes accompanying attention to perceptual objects, as shown by these figures, are:

(1) A tendency to reduce the length of the inspiration. The respiration of sleep and of low mental activity in general has been found to be characterized by its long inspiration and short expiration. As the mental excitement rises the latter component increases, the former decreases. The same tendency appears here as attention succeeds inattention. In five subjects the decrease is an absolute one, sometimes of marked extent—*e. g.*, 1.21 to .74 secs.; in the remaining cases, (A) and (F), though the figures show an absolute increase, a comparison of the durations for the full respiration [3.59—4.41 secs.; 5.35—5.58 secs.] reveals the fact that there has been at the same time a relative decrease.

(2) There is a general increase in the relative length of the expiration. In four subjects this increase is also positive; in the fifth, in which an absolute decrease appears, there is at the same time a relative increase in length (1.41–3.81 secs.; 1.38–

3.43 secs). The sixth and seventh do not conform to this type. The time-relation of inspiration and expiration is characteristic of the state of mental activity. Respiration during sleep is marked by relatively slow inspiration and rapid expiration. In drowsiness and after a full meal the same predominance of the inspiration is noticeable. With the increase of cerebral excitement the inspiration grows rapid, direct and strong, the expiration slow and interrupted. The extreme forms are seen in the sudden inspiratory sob of weeping, followed by the prolonged expiration, broken by repeated suspensions of the breath; or in the similarly swift influx of air in laughter with its subsequent series of alternate suspensions and expulsions. Both the strong inspiration and the retardation of contraction during expiration point to an increased expenditure of energy as compared with the phenomena of sleep, where the innervation is sufficient only to inflate the lungs slowly, and where the contraction of the chest at its close is not interfered with by the contraction of the voluntary muscles.

(3) There is a general increase in the rapidity of the respiration. This is also a characteristic of heightened mental activity. The exceptions to it are noted under section (4).

(4) When the respiration decreases in rapidity the retardation is due not to a proportional increase in time of all the component phases, preserving the normal type, but to an abnormal suspension of the breath with the lungs inflated [A. .33—.87 secs.; E. .24—.36 secs.], to a prolongation of the expiration [A. 1.06—1.45 secs.; E. 1.03—1.42 secs.], or to an exaggeration of the respiratory pause [F 1.71—2.00 secs.], all of these indicating an inference with the regular periodic innervation of the organic muscles.

(5) There is a moderate tendency to superficiality of respiration. This is extremely marked in the case of three subjects. In three others it altogether fails to appear. Two of these are characterized also by slow respiration and retardation of the respiration.

(6) In general, the attitude of attention is characterized by disturbance of function. Every departure from the normal type is significant as indicative of an interference with the automatic

character of the respiration. The breathing during attention is marked by just such wide and frequent but irregular fluctuations. This will be made more apparent by the following table of the comparative variations in time and depth during the normal and experimental periods.

	Normal.		*Attention.*	
	Time.	Depth.	Time.	Depth.
A	1.01 secs.	13 min.	3.15 secs.	17 min.
B	.67 "	35 "	1.01 "	45 "
C	.45 "	6 "	.56 "	7 "
D	1.05 "	5 "	2.80 "	36 "
E	.82 "	9 "	2.68 "	25 "
F	.73 "	8 "	1.16 "	5 "
G	1.05 "	10 "	1.75 "	18 "

The changes in variability are more readily appreciable than those in average character. The variation in the length of individual respirations has increased to more than double the normal. This increase in variability is uniform; each individual record of every subject shows it. There is a similar increase in the extent of the variation in depth, amounting in extreme cases to seven times the normal, and failing to appear only in a single case, where the variations in normal and attention phases are as six to five.

Characteristics of the Pulse and Volume Curves.

As throughout the whole series of experiments the plethysmographic and sphygmographic records unite in one volumetric curve, an exact analysis of their separate character is frequently impossible, the change in strength of heart contraction and the secondary features of the pulse wave being obscured by simultaneous changes in the volume curve. A number of significant features, are, however, definitely determinable. There is, without exception, an immediate increase in the rapidity of the rhythm at the beginning of the attention period, succeeded by a more gradual and enduring decline. This slowing usually continues until a point below that of the preliminary period is reached, when there is again a gradual increase

towards the normal. The following table shows the extent and duration of the changes for the various subjects concerned. The figures give the averages for successive periods of twelve seconds each.

	Normal.	*Attention.*	
A	72.5 per minute.	72.5 per minute.	70.0 per minute.
A	87.0 " "	90.5 " "	80.0 " "
A	72.5 " "	77.5 " "	75.0 " "
A	80.0 " "	82.5 " "	80.0 " "
B	75.0 " "	82.5 " "	77.5 " "
C	62.5 " "	67.5 " "	65.0 " "
C	62.5 " "	65.0 " "	55.0 " "
D	95.0 " "	102.5 " "	92.5 " "

The maximum increase is reached within the first ten seconds in the case of all subjects; and the whole acceleration is usually confined to a period of twenty-five seconds. In some cases the decline is more gradual and reaches the normal only towards the close of the experiment. With the greater number the retardation is more rapid and passes beyond the normal, in some cases to a greater extent than the primary acceleration rose above it.

There is, in the case of most subjects, an increase in the interference of the respiratory period with the volume curve, which tends to obscure the character of the pulse-beats. So far as has been observed, the effect of attention upon the strength of heart contraction is variable. With three of the subjects there is a reduction in the extent of the stroke, independently of the variations in the volume curve or the respiratory changes. In subject D there is an increase, together with a marked irregularity, in extent, and in a similar inconstancy in the rhythm of successive beats. This perhaps marks, in one of D's temperament, the presence of a rather strong emotional element due to nervous excitement.

Simultaneously with the primary acceleration of the pulse occurs a rapid and extensive fall in volume, reaching a minimum at the end of a period varying from six to ten seconds, followed either by a gradual and more continuous rise towards

the normal line, or by a series of subsidiary waves, finally approximating to that which characterized the preliminary period. These wave-like and frequently rhythmical changes of volume find an apt interpretation in the hypothesis of fluctuation, each pulse of close and accentuated attention being followed by a period of distraction and relaxation; and the prevalent subsidence of the waves in the latter part of the experiment may indicate the gradual failing of attention through fatigue.

The effect of attention upon the interference of the respiratory period is variable and obscure. In some cases the rhythmical increase and diminution of volume is reinforced, even when the respiration grows more superficial; in others there is a reduction in the interference, especially if the breathing becomes more shallow. In others again no definable alteration in character appears.

Muscle Changes in Perceptual Attention.

These are typical and uniform. The changes consist, in general, of an exhibition of movement and tendency to relaxation of the muscles, indicating a lowering in the static tonicity of the muscular system. In the preliminary period the finger record is usually effected by the respiration, a slight extension of the arm accompanying each inspiratory elevation of the chest, and being followed by a corresponding contraction during expiration. These changes are uniformly reduced and frequently obliterated during the period of attention, though the respiration suffer no diminution in depth. The preliminary period is usually marked by a constant *subsultus tendinorum* as well as by more massive spasmodic contractions and expansions of the muscles. These are reduced and frequently disappear during the attention period. The tendency to relaxation does not always appear as a positive extension of the finger. In some experiments the finger will be found to remain stationary during attention; in some others a continued or intermittent contraction is manifested. But in every such case there is a *relative* relaxation. Where the preliminary period shows a tendency to contract—if strong, it continues, but in reduced

degree,—if slight, it disappears or is replaced by moderate extension. Where the preliminary period shows no change, the passage to attention is marked by extension, slight in some cases, great in others; and where the first period is characterized by continuous extension it is immediately and strongly reinforced at the beginning of the experimental stage. These expansions and contractions during the earlier period are probably due to the fact of insufficient time having been allowed for the muscles to reach a state of equilibrium. But the effect of the passage to attention is seen as clearly in the altered direction of the curve as it is when the preliminary period is marked by rest.

A negative illustration of the muscular changes accompanying attention appears at the close of the period when the tremors, irregularity in contraction and expansion, respiratory influence, and general tendency to contraction again set in.

Functional Changes during Attention with a Strong Sensory Element.

In the preceding series the object of attention was a neutral one; there was nothing in the ticking of the watch which was *per se* interesting. The attention was wholly secondary and voluntary; the subject deliberately abstracted from all other objects and focused his attention upon this dull, monotonously-repeated sound.

There will evidently be a new element introduced into the mental complex if a stimulus be selected which besides the derived interest of voluntary attention, comes to the subject with a distinct of its own, one which by its unusual or pronounced sensory character arouses a certain emotional element and fixes the attention by its own power. Such a combination of voluntary and involuntary attention elements was sought by tracing upon the subject's cheek with the tip of a pencil a series of geometrical figures which the subject endeavored to discriminate and recognize by the sense of touch alone. The stimulus was novel; it involved a continuous sense stimulation apart from the volition of the subject; and with all the persons concerned

in the experiments it seized and held the passive attention as simple touch sensation, apart from the character of the lines drawn. There was required in addition a close and constant effort to recognize the various forms which were one after another inscribed upon the skin. These experiments were conducted with five subjects with the following results:

AVERAGE DURATION OF THE PHASES OF RESPIRATION.

1. Normal.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.76 secs.	.22 secs.	.58 secs.	1.22 secs.
B	1.27 "	.31 "	1.40 "	1.46 "
C	.56 "	.17 "	1.03 "	1.17 "
D	1.08 "	.27 "	.72 "	.72 "
E	.63 "	.22 "	.58 "	.58 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	2.78 secs.	25 mm.	D.—	2.79 secs.	25 mm.
B	4.45 "	37 "	E.—	2.01 "	20 "
C	2.93 "	25 "			

2. During Attention.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.49 secs.	.36 secs.	.85 secs.	1.11 secs.
B	1.14 "	.36 "	1.48 "	1.90 "
C	.47 "	.56 "	1.34 "	.83 "
D	.94 "	.18 "	.94 "	.85 "
E	.49 "	.54 "	1.39 "	1.12 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	2.81 secs.	13 mm.	D.—	3.91 secs.	20 mm.
B	4.91 "	30 "	E.—	2.50 "	20 "
C	3.16 "	13 ,,			

The comparative changes here are of the same type as those which were found to characterize the passage from rest to purely voluntary attention; but they are more constant and of greater extent.

There is first a reduction in the relative length of the inspiration, and an increase in that of the expiration. But in both

these components the change is more invariable than in the preceding series and of greater extent. In the present form of attention it is throughout positive as well as relative; the extent of the reduction, also, is greater in the present series than in the earlier one. In the case of the expiration, again, there is a more constant increase in duration, every subject showing both a relative and a positive increase, and this increase is of greater extent than in voluntary attention.

There is in every case a decrease in the rapidity of the rhythm. In all cases but one—E. 2.01–3.50—this increase is relatively slight. Voluntary attention, on the other hand, was characterized by an increase in the rapidity of the respiration.

The changes in the respiratory pauses are variable; in some objects the averages show an increase, in others a decrease appears. These figures are among the least significant of the record. What characterizes the curves of this composite attention is essentially departure from type, disturbance of function, which a system of averages may as readily tend to obliterate as to preserve. This feature of the breathing during attention appears more plainly by a comparison of the extent of the variations in respiration during the contrasted periods.

	Normal.		*Attention.*	
	Time.	Depth.	Time.	Depth.
A	1.10 secs.	10 mm.	3.40 secs.	22 mm.
B	.62 "	4 "	2.92 "	20 "
C	.45 "	2 "	.57 "	6 "
D	.22 "	3 "	.45 "	4 "
E	.45 "	4 "	2.90 "	9 "

The increase of variation both in the rapidity of the rhythm and in the extent of inflation of the period of attention over that of the preliminary period is evident. These fluctuations will also be found greater than those which accompanied voluntary attention. There is at the same time a uniform reduction of considerable extent in the depth of the breathing. The same general tendency is present also in the previous form of attention, but is found lacking with three of the subjects.

Pulse and Volume Changes.

Few changes in the character of the pulse are to be observed in these records. The apparent strength of stroke remains unaltered during the two periods. Slight irregularities in the interval between successive strokes appear in one or two instances, and with one subject there is a slight reduction in the strength of the stroke. In the rate of the pulse beats, before and after the beginning of the experiment, and at successive periods during its continuance, a new set of changes is met with varying from the normal of the preliminary period in a direction opposite to those which appeared in the previous series. With all the subjects who took part, the tracing of the figures upon the cheek is accompanied by a retardation in the rate of the pulse, usually immediate, but in some instances delayed for several seconds, followed by an increase again towards the normal. In some cases the diminishing retardation continued throughout the period of stimulation; in others an acceleration beyond the rate of the preliminary stage was reached; in one record a secondary wave of retardation appears. These changes are independent of the fluctuations which occur in the volume curve. They are altogether unexpected; the addition of the sensory stimulus, bringing with it a certain emotional tinge, might lead one to expect an increase of the acceleration which was found in the previous series instead of the retardation which actually obtains.

Muscle Changes.

The same muscle changes appear here which characterize the earlier form of attention. In all six subjects there is an alteration in the direction of the curve at the beginning of the attention period. These changes do not always present a positive relaxation of the hand. In those instances in which a gradual contraction continues throughout the previous period, the new direction appears as a diminution in the rate of contraction. When the contraction is slight the subsequent curve shows either a state of equilibrium, or a faint expansion. When a previous tendency to expansion exists it is appreciably reinforced from the beginning of the new attitude onward.

There is, also, in the preceding experiments a tendency to inhibition of movements manifested in the absence of slight irregularities in the curve, and the dampening of the *subsultus tendinorum*. The respiratory period is less marked during attention than in the preliminary period, occasionally disappearing. These muscle changes are not invariably present, and different records fail to show any change of condition in the passage from inattention to stimulated attention.

FUNCTIONAL CHANGES DURING RECALL OF PAST EVENTS.

The preceding experiments were concerned with objects of perceptual attention; the present and succeeding sections abstract from objects of sense, and have to do with reflection and more purely intellectual processes.

The method of conducting the experiments was simple. The subject sat as before with closed eyes, the instruments adjusted upon his body. After a preliminary period of inactivity, he was required to recall various groups of objects, such as the instruments which he had seen in a certain case, the substance of a late lecture, the experiences of a particular day in the past, and the like. At the close a final period of rest was given; and at the end of each experiment the observer made full notes of his subjective experiences.

In recall the changes in the character of the respiration are of the same general type as those found present in perceptual attention, but are more variable in direction, of slightly less extent, and present more individual variations. The quantitative relation of the phases is shown in the following tables:

1. Normal.

	Inspiration.	Insp. Pause.	Expiration.	Ex. Pause.
A	.76 secs.	.22 secs.	1.37 secs.	1.35 secs.
B	.72 "	.67 "	1.57 "	1.30 "
C	.76 "	.36 "	1.37 "	.90 "
D	1.12 "	.36 "	1.17 "	.40 "
E	1.26 "	.76 "	2.92 "	.63 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	3.70 secs.	29 mm.	D.—	3.05 secs.	52 mm.
B	4.26 "	23 "	E.—	5.57 "	37 "
C	3.39 "	30 "			

2. Recall.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.49 secs.	.27 secs.	1.08 secs.	1.03 sec.
B	.54 "	.18 "	1.80 "	.81 "
C	.30 "	.54 "	1.03 "	1.35 "
D	.63 "	.40 "	1.26 "	.54 "
E	.94 "	.63 "	1.71 "	.63 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	2.87 secs.	22 mm.	D	2.83 secs.	37 mm.
B	3.33 "	32 "	E	3.91 "	24 "
C	3.23 "	13 "			

Variations in Respiration.

	Normal.		*Recall.*	
	Time.	Depth.	Time.	Depth.
A	.45 secs.	6 mm.	.90 secs.	19 mm.
B	1.35 "	4 "	.45 "	9 "
C	.45 "	4 "	.70 "	9 "
D	.90 "	10 "	.22 "	6 "
E	1.35 "	4 "	.70 "	9 "

The general increase in irregularity of depth is evident here. The extent of this increase is magnified when it is remembered that there is at the same time a reduction in the average depth of respiration. It is probable that this irregularity is chiefly a physiologically originated phenomenon. The rapid superficial breathing which accompanies continued effort to recall, affords insufficient aëration of the blood; the series is broken in upon here and there by one or two fuller respirations stimulated by incipient asphyxiation. In some cases, however, an irregularity appears which is more closely related to the consciousness aspect of the experience.

The simple effort involved in all recall is expressed in the quickened shallow breathing, which increases in rapidity and superficiality with the difficulty involved in the process. The change here is rather in the direction of increased uniformity than of variation from it. When the objects of recall are not neutral, such as remembering a series of numbers or the instruments in a certain case, but are colored with a strong emo-

tional element; wide irregularities in the character of the individual respiration are presented, similar to those which appear under strong sensory stimuli. The subject is, in a less intense degree, living over again the experiences which he is endeavoring to recall, and the disturbance of function which accompanied their original occurrence is partially reëstablished here.

There are therefore two elements in recall to be kept separate, as affecting the character of the bodily functions: (1) the effect of attention, the simple intellectual effort requisite to the recall of indifferent objects; (2) the effect of personal relation to the objects of recall.

The character of the functional change varies from individual to individual. In some cases, instead of the superficial respiration which characterizes most subjects, there is found a rapid, regular but more profound respiration than in the normal. With other subjects there is a great reduction in depth, the breathing at times being almost suspended.

While the degree of functional disturbance varies from subject to subject, within the individual record the variation increases with the effort requisite for recall. A sense of ease and freedom is accompanied by slight variation from the normal; with increasing difficulty the deflection of the curves becomes greater and greater. This is seen most clearly in those cases in which the emotional element is got rid of, and the changes are wholly due to the intellectual effort involved. This condition is approximated to in the following series, in which the subject was required to perform certain arithmetical calculations of varying complexity.

At present we may say that the effort to recall a series of past events is accompanied by a rapid superficial breathing, marked by a swift short inspiration and an interrupted and prolonged expiration; that with the decrease in depth there is a greater irregularity in the duration of successive respirations, in the depth of the breathing, and in the time relations of the component phases of the individual respirations; and that as the process of recall becomes more difficult and involves greater effort the extent of the variation from the normal increases.

Also, that while simple recall of indifferent objects is ac-

companied by a quick slight breathing which may be more uniform than the normal, the recall of things which involve a strong emotional element is characterized by irregularity of rate, depth and form, the nature and extent of the irregularities depending upon the emotional character of the objects recalled. The average rapidity of the respiration is likewise without exception increased; and there is an absence of the suspensions with full or deflated lungs, or in the midst of expiration, which frequently characterized the former mental attitude.

Characteristics of the Pulse and Volume Curves.

The type of change here seems to vary. The pulse-beat is in some cases at first increased, then slowly reduced to the normal towards the close of the experiment. With others there is an immediate slowing of the pulse rate gradually accelerating towards the normal again. These two types of change are present in the same individual at different times. In all cases in which an immediate increase in rate appears the process of recall was attended with difficulty. In those marked by a fall it was either easy or no mention was made of effort. The pulse rate frequently presents the form of a series of waves, alternately rising above and falling below the normal of the preliminary period. It is possible that these may indicate a series of fluctuations in the intensity of the attention and of the effort to recall.

In almost all cases the pulse stroke is shortened during recall. Frequently this change is immediate and definite, in some cases the reduction amounting to one-third or even one-half of the previous extent of stroke. There is usually with this a simultaneous reduction in the depth of the breathing, which, as a purely physiological phenomenon, is accompanied by such a reduction in the pulse stroke, but the change under these conditions is concomitant with a rapid rise in volume, and the reduction in pulse stroke is proportional to the extent of the volume increase. In the case of recall, however, the reduction is accompanied by a decrease in arterial tension, marked by a fall more or less rapid and extensive in the volume curve. It also

occurs when the respiration is increased in depth instead of becoming more superficial.

The form of the pulse wave also undergoes alteration. The preliminary period is characterized by a full strong stroke, followed by an immediate and sharp fall towards the dicrotic crest, making an acute apex; in the period of recall the shorter stroke is succeeded by a slow delayed subsidence, the tracer dragging on towards the next stroke before a decided fall takes place giving a blunted form to the arterial wave.

The volume curve shows less tendency to typical forms of change than in the previous experiments. There is usually an immediate fall in volume at the beginning of the period, continuing from five to ten seconds, and followed by a more gradual rise, the two phases being repeated several times during the course of the period, usually with a decrease in the width of the variation towards the end.

These wide fluctuations in the volume curve during recall are the most constant factors which appear. Since the transition from the previous diffused mental state to the concentration of attention in recall is typically marked by a fall of greater or less extent in the arm volume, the occurrence of these repeated waves suggests a fluctuation in the degree of effort made, the attention coming and going in pulses.

The interference of the respiratory period increases during recall. In normal cases its influence increases and diminishes with the depth of the respiration; suspension of the breath causes it to disappear. Here, on the contrary, it grows more pronounced even when the breathing simultaneously grows more superficial.

As relief there is a slowing of the respiratory rhythm, an increase in the depth of the breathing and of the duration of the inspiration with a relative reduction in that of the expiration, an increase in the extent of the pulse stroke, a slowing of the pulse rhythm and a rise in the volume of the arm.

Muscle Changes during Recall.

The changes here are similar to those found present in the earlier series on perceptual attention. The transition from the

preliminary effortless state to that of strenuous recall is marked by a change in the direction of the muscle curve. This is manifested as before in a reduction in the degree of contraction, a disappearance of it, or a substitution of expansion, in cases in which a contraction appears in the preliminary period, and a reinforcement of the tendency of expansion where such already existed. This change in the direction of the curve is very uniform. There is also a reduction in the greater irregularities which usually characterize the normal curve, and a disappearance or dampening of the *subsultus tendinorum*. The essential features of this curve, then, are a tendency to a relaxed condition of the muscles, and an absence of muscular excitement, marked by a quiet even curve without massive changes or tremors.

Functional Changes during Calculation.

The method of experimentation here is varied only by the substitution of a new form of stimulation. The subject was required to perform certain arithmetical calculations instead of recalling a series of past events. We may therefore proceed immediately to a consideration of the particular changes in function which present themselves.

1. Normal.

	Inspiration	Insp. Pause.	Expiration.	Exp. Pause.
A	.72 secs.	.22 secs.	1.39 secs.	1.35 secs.
B	.76 "	.31 "	1.24 "	1.12 "
C	.67 "	.40 "	1.17 "	1.35 "
D	1.26 "	... "	1.89 "	1.98 "
E	.67 "	.49 "	.85 "	1.11 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	3.68 secs.	29 mm.	D.—	5.13 secs.	81 mm.
B	3.43 "	34 "	E.—	3.12 "	15 "
C	3.59 "	20 "			

2. Calculation.

	Inspiration.	Insp. Pause.	Expiration.	Exp. Pause.
A	.49 secs.	.22 secs.	1.12 secs.	.90 secs.
B	.22 "	.31 "	1.12 "	.36 "
C	.67 "	.22 "	1.26 "	.37 "
D	.58 "	.13 "	1.62 "	1.89 "
E	.45 "	.45 "	.85 "	.85 "

	Total Resp.	Depth.		Total Resp.	Depth.
A	2.63 secs.	22 mm.	D.—	4.22 secs.	61 mm.
B	2.01 "	13 "	E.—	2.60 "	12 "
C	2.51 "	25 "			

There appears here, as in the previous experiments, an increase in the rapidity of the respiratory rhythm; but while in both series there is a reduction in the rate of the respiration, in the former the relation of the component phases was significantly altered, while here there is little variation from the tpye of normal unstimulated respiration. In one component, however, there is a great change, the respiratory pause is invariably shortened, usually to a great extent. In normal breathing it is frequently accentuated, the expiration being followed by a distinct period of quiescence before the succeeding inspiration. During calculation this pause is either lessened or altogether disappears; inspiration follows expiration with scarcely a break. This feature is significant. Exaggerated pauses are characteristic of one attitude of mind, diminished pauses of a typically different state. In any sudden surprise the breath remains suspended, inhibited sometimes for several moments, till the shock passes by. The same suspension appears in more exaggerated forms in fear and terror. In close attention—in the effort to catch a faint sound, for example—it is also a characteristic feature. These states of mind are marked by a general inhibition of function which extends to temporary cessation of the respiratory process, until the oppression of the lungs finds relief in renewed respiration. In all work—expenditure of effort—on the other hand, there is an increase of functional activity. The heart beats faster and stronger, the respiration grows deeper and more rapid, and the glandular secretions of the skin become more copious during muscular exertion. And the same change, in greater or less degree, accompanies increased intellectual activity. In exciting emotions the respiration is deep and rapid with lungs inflated, inspiration and expiration succeeding each other without pause.

In more purely intellectual activity, the breathing, which is usually more superficial as well as more rapid, is marked by an

almost complete obliteration of the respiratory pause. This rapid, equable and slightly superficial respiration may be conducive to a more constant supply of blood to the brain, the sudden and great expansion of the lungs in deep respiration causing too great a fluctuation in the quantity supplied to its vascular tissues for continuous cerebral activity.

The uniformity of respiration during calculation will further appear from the following table of variations during the two periods:

	Normal.		*Calculation.*	
	Time.	Depth.	Time.	Depth.
A	.22 secs.	4 mm.	.66 secs.	19 mm.
B	1.10 "	17 "	.90 "	20 "
C	.70 "	7 "	.22 "	5 "
D	1.10 "	12 "	.70 "	30 "
E	.90 "	4 "	.70 "	6 "

The variation in depth is usually greater in the more highly stimulated conditions. This is probably due to two different causes. These are, first, the physiological one of periodically increased innervation from incipient asphyxiation, the more superficial respiration being insufficient for the needs of the system; and, second, the psychological one of fluctuation in the intensity of the effort required in calculation periods of close attention with rapid, regular, superficial respiration alternating with periods of relaxation indicated by the fuller breathing of relief. In some cases no such rhythmical series appears, the respiration growing continually more superficial as the calculation proceeds. This may indicate a continued attention with increasing effect, as both the shallowness of breathing and diminution of volume are found to bear close relation to the difficulty of reckoning involved in the problems given.

Pulse Volume Curves.

The beginning of calculation is in all cases accompanied by an acceleration of the pulse rate, sometimes of great extent, and continuing throughout the larger part of the period. The form of this acceleration varies greatly from individual to individual and from record to record.

The rise is sometimes immediate and rapid, succeeded either by a similarly sudden fall or by a sustained increase in rate. Sometimes the acceleration is slow, maintained during a considerable period, and falling again gradually towards the normal. In some cases the rise is developed for several seconds after calculation begins. The return to the normal is usually reached within a minute's calculation. In some cases the acceleration dies away before one-half the time of calculation has expired. At relief a fall below the normal appears with occasionally a secondary wave of acceleration. The following figures give the average rate before calculation and for successive periods of twelve seconds during calculation:

	Preliminary Period.	During Calculation.		
A	62.5 seconds.	67.5;	80.0;	85.0 secs.
B	72.5 "	72.5;	74.5;	75.0 "
C	77.5 "	77.5;	82.5;	85.0 "
"	75.0 "	82.5;	75.0;	—— "
D	57.5 "	65.0;	62.5;	62.5 "
"	65.5 "	70.0;	75.0;	75.0 "
E	60.0 "	65.0;	67.5;	65.0 "
"	75.0 "	77.5;	80.0;	75.0 "
F	50.0 "	55.0;	60.0;	60.0 "

An almost constant feature of the pulse during calculation is the reduction in height of stroke. This may be due either to a weaker ventricular contraction or to an increase in the arterial tension. The latter condition accompanies any voluntary reduction in depth or complete suspension of the respiration. The volumetric curve shows an immediate increase in curve volume, due to congestion of the blood in the smaller veins and arteries, and a reduction in the height of pulse wave—which may finally become obliterated—due to the continued increase in arterial tension. If then the respiration uniformly becomes more superficial during calculation, such a reduction of the pulse wave is to be expected; it becomes a secondary phenomenon, and, except as depending upon the primary change in respiration, is relatively insignificant.

But in these records it appears independently of the respira-

tory changes, occurring when the respiration is increased in depth as well as when there is no appreciable variation in it. Compare it again with the concomitant changes in the volume curve. This is found to alter as the character of the respiration changes, and as the volume changes the form of the pulse also undergoes alteration. But the changes which appear during calculation seem to be independent of the changes in the volume curve as well. A reduction in the height of the pulse wave is the physiological concomitant of increased arterial distension; but here it occurs simultaneously with its fall in arm-volume which normally marks the increased mental activity during calculation. It is present when there is no appreciable change in arm-volume, and it persists both in the rising and falling of the curve. The reduction of the pulse wave, therefore, since it appears even with increased respiration and a falling volume curve, both of which should tend to reinforce it, is a direct effect of the central change obtaining during calculation.

The volume changes are analogous to those of the preceding series. Decrease is more or less rapid and extensive, continuing for a variable period, and followed either by a continuous, gradual rise, or by a series of wave-like fluctuations in volume.

Muscle Curve.

The changes in the muscle curve are usually of slight extent and identical in type with those described in the preceding experiments upon recall. They are not invariable in direction nor so constant as in recall and perceptual attention. Occasionally there is an increase in the tremor of the muscles, occasionally also a greater irregularity in the form of the curve during calculation than in the preliminary period; and in one or two instances a slight tendency to contraction appears, or a previously existing contraction is reinforced.

In general, however, these changes are the same as in those of recall. Contraction and muscle tension are replaced by relaxation and extension of the fingers. This is shown also in the contraction which frequently appears again at the close of the period, the static muscle tension recovering its normal tone

as soon as attention is drawn from the process of calculation. With this relaxation goes a diminution of muscular tremor and a reduction in the irregularities of the curve. This relaxed condition during close mental effort indicates a reduction in the degree of reflex stimulation throughout the organism, and inferentially a greater efficiency to the central nervous discharges. Tension represents expenditure of energy; there is a continual drainage of nervous force to the peripheral system when this is in a state of activity, and the lowering of this expenditure—which characterizes the types of activity here investigated—leaves free a wider margin of available energy for the central activity.