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Research Article

A STUDY OF FACTORS (EMOTIONAL) RESPONSIBLE FOR CHANGES IN THE PATTERN OF SPONTANEOUS RHYTHMIC FLUCTUATIONS IN THE VOLUME OF THE VASCULAR BED OF THE FINGER TIP [1]

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When rhythmic changes in the volume of fingers (alpha waves), toes, and ears were first studied, the records seemed to fall into two main types, those with large changes and those with small. There was reason to think that these differences corresponded to the psychological type of the subject—a pattern of consistently large changes occurring in persons with volatile temperaments, and of consistently small changes in steady-going, phlegmatic ones. Investigation into the mechanism of these rhythmic changes disclosed the fact that they were independent of fluctuations in blood pressure (1) but were dependent upon changes in the size of the small blood vessels (2). It became clear that these were in turn dependent upon the uninterrupted activity of the sympathetic nervous supply (3). Information recently secured showed, furthermore, that the pattern of changes was not unvarying in an individual, but could be now of one type and later on of another. Such transformations occurred even when external factors such as temperature and humidity were kept constant and disturbing psychological influences originating in the immediate environment were kept at a minimum. Control over all these elements was maintained because of their known importance as stimuli, capable of modifying the basic pattern by inducing periods of vasoconstriction.

Once the detectable environmental influences were stabilized, cause for the lability of patterns must lie, it seemed, in what was going on in the mind of the person under examination. If parallel records could be compared, (*a*) those of the pattern of changes in volume of the finger with (*b*) those attempting to describe what was going on in the subject's mind, a clue to the influence of the latter, (*b*), upon the former, (*a*), might be obtained. Because the task of setting down and analyzing all that was going on in a subject's mind was obviously beyond the scope of this study, one aspect of mental activity was selected as deserving primary consideration. This was the emotional status. The point should be made emphatic that the objective of this study was limited to a comparison between emotional status and the changing pattern of activity in the peripheral blood vessels. The object was to ascertain whether particular patterns recurred repeatedly and could be identified with particular emotional states.

MATERIALS AND METHOD

The apparatus employed to obtain plethysmographic records of the changes in volume of the finger tips was that of Turner (4). Certain alterations described by Neumann (1) were introduced because they provided easy portability and made it possible to obtain records in an environment completely familiar to the subject. The tip of the left index finger only was measured. Its volume was ascertained beforehand. The distance in the photographic system was adjusted so that the records obtained represented effects produced by 5 cc. of finger tip. This device was convenient and allowed direct comparison of records from fingers of different sizes. The subject was recumbent when the records were made and the finger tip was at the level of his heart. Since air-conditioning equipment was not available, the investigations were conducted during the spring when, by selecting comfortable days, the temperatures fell within 5 degrees of 75° F.,

[1] This is the 11th paper reporting the results of studies of the small blood vessels and related subjects.

[2] The Bureau of Medicine and Surgery does not necessarily undertake to endorse views or opinions which are expressed in this paper.

and the relative humidity between 48 and 79 per cent. Records were not made until at least 3 hours after eating. After the plethysmographic cup had been applied to the finger, subjects rested for about 20 or 30 minutes. Then records were taken for 15 minutes on all but a very few occasions when, for one reason or another, the time had to be somewhat curtailed.

Ten males, 8 psychiatrists, a psychologist, and a physiologist, fully acquainted with the program and problem of this investigation, volunteered to act as subjects. They were willing, of course, and trained to report fully such information as was required. Their ages varied from 28 to 39 years, the average being 33 years. A total of 54 records, an average of 5 per person, was obtained over a period of 10 weeks. The apparatus was placed in a room separated by a sound-proof wall from that of the subjects, to avoid an emotional reaction likely to be created by the presence of an operator and the machinery (5).

After each record was obtained, the subject, in response to careful questioning, described his dominant emotion. Special attention was paid to the presence of persistent emotions. In addition, his behavior just before and during the recording was appraised, particularly in terms of restlessness, degree of cooperation and of curiosity about the procedure. Beside his dominant emotion, its type, intensity, onset, course, and cause, his less dominant ones or the presence of a combination of emotions were likewise recorded. The subjects were also asked to describe the more dominant emotions experienced during the preceding 24 hours. An impression of their general physiological status was obtained by inquiring about fatigue, minor somatic complaints, headache, abdominal discomfort, unusual degree of muscular tension, palpitation, and perspiration.

For the purpose of this investigation, certain emotions received the following definitions. Contentment implied a state of moderate happiness without special cause and without awareness of agreeable, somatic association. Elation was taken to imply happiness, but in this case as a reaction to an external or psychologic event or release from anxiety. Beyond a feeling of physical well-being, elation was usually considered as being free from somatic symptoms. Sadness meant mild unhappiness, unalloyed with other emotions, especially anxiety, and presenting no diurnal variation in mood, no decreased physical activity, no retardation of movement or thinking, no accompanying somatic manifestations. Anxiety was fear or apprehension, usually with restlessness and a feeling of muscular tension (6). Other somatic manifestations, such as tremor, palpitation, and axillary perspiration, were recognized as present in anxiety, but the intensity of this emotion was never great enough to permit outspoken accompaniments. Depression meant unhappiness plus an admixture of other affects, such as anxiety or resentment. Resentment itself implied a frequently formed configuration of emotions in which anxiety, unhappiness, anger, and suspicion were present, with their corresponding somatic appearances.

RESULTS

All subjects exhibited continuous rhythmic variations in volume of the finger tip. These fell into 5 main types (2): pulse waves, respiratory waves, and alpha, beta, and gamma waves. The first 2 are dependent on cardiac and respiratory activity; the latter 3 are independent of other recognized physiological phenomena. Alpha waves may be described briefly as the plethysmographic representations of rhythmical somewhat *unequal* variations in the size of a finger or toe. They occur 5 to 8 times a minute. Their size may attain that of pulse waves recorded from the same part. Beta and gamma fluctuations resemble these but are larger and occur less frequently, requiring long, continued recording for their full development. Their meaning has not yet been investigated.

In the present records, the average number of alpha deflections for all subjects was 5.4, as compared with the average 7.9 per minute formerly published (2). This difference is owing presumably to the study of a different group of subjects, and, in part, to lack of uniformity exhibited by these individuals. Such differences will continue to be discovered because the individuals and groups that have been studied are not representative of a freely selected random sample of persons.

Some records were obtained in which almost all of the *alpha* deflections were small; in others, there were many large deflections; and in still others, there was a predominant number of large deflections. The records could accordingly be divided into the customary 3 types (2). In Type I were those which consisted almost entirely of small deflections, with an average size of 13 cu. mm.[3] or less. In Type II, there were fewer small and more large deflections; the averages in the various individual records ranged between 13 and 17.9 cu. mm. Type III records exhibited many large ones, raising the average size above 18 cu. mm. These 3 types are, for the most part, clearly distinguishable on casual perusal of the tracings. The quantitative limitations have been arbitrarily imposed to aid in the classification of borderline records. The important classification

[3] In this paper, changes in volume (alpha deflections and pulse waves) are given in cubic millimeters per 5 cc. of part.

is among the principal types—small, intermediate, and large deflections. There is obviously no essential difference between a record having an average size of 17.9 cu. mm. and one in which the average is 18 cu. mm.

Independent of variations in the size of alpha deflections were variations in the size of the *pulse* waves. These were recorded simultaneously, and on the tracings appeared as minor, rapid fluctuations (equal in rate to the cardiac beat), modulating the slower and larger alpha waves.

There were records in which all the pulse waves

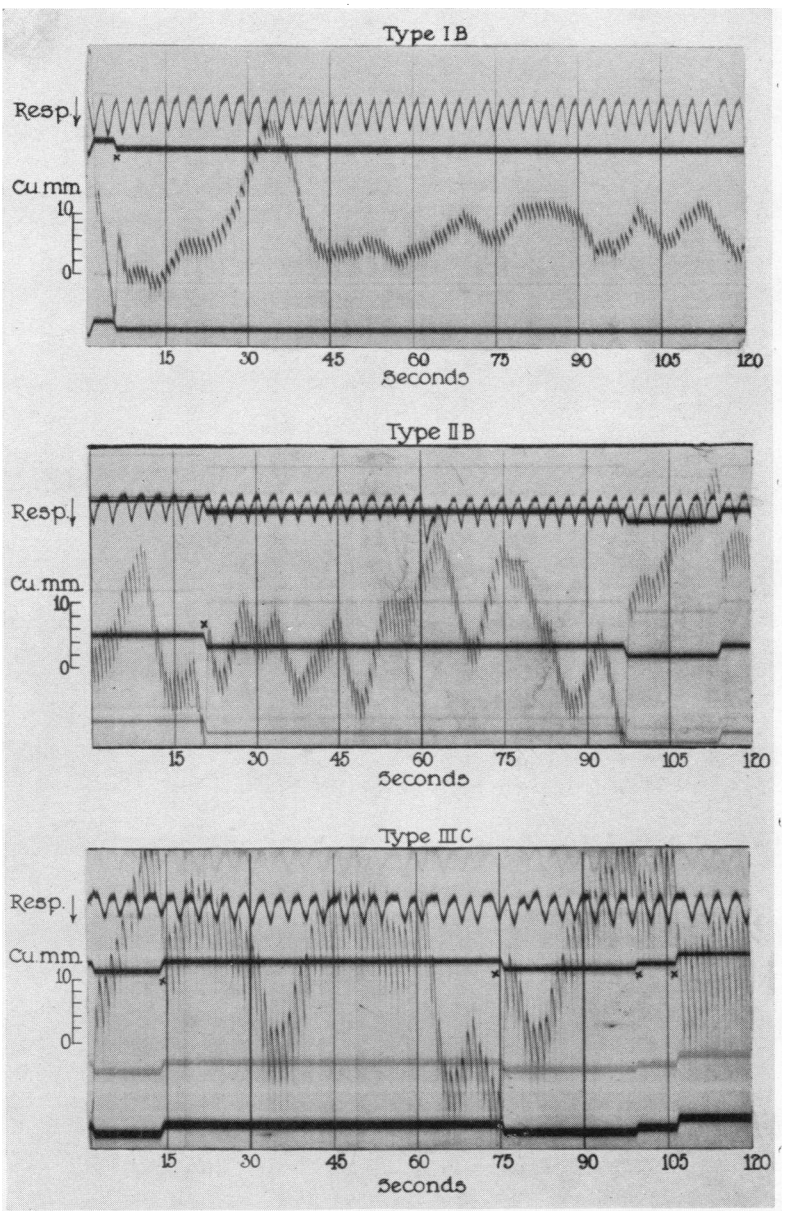

FIG. 1. ORIGINAL RECORDS ARE REPRODUCED TO ILLUSTRATE VARIOUS TYPES OF ALPHA WAVES

In I B, the pulse waves are of uniformly small volume; whereas in III C, there is a considerable variation in volume through the record. The downward direction of the arrow indicates inspiration. Changes in the position of the base-line, to keep the record in the optical field, are indicated by X.

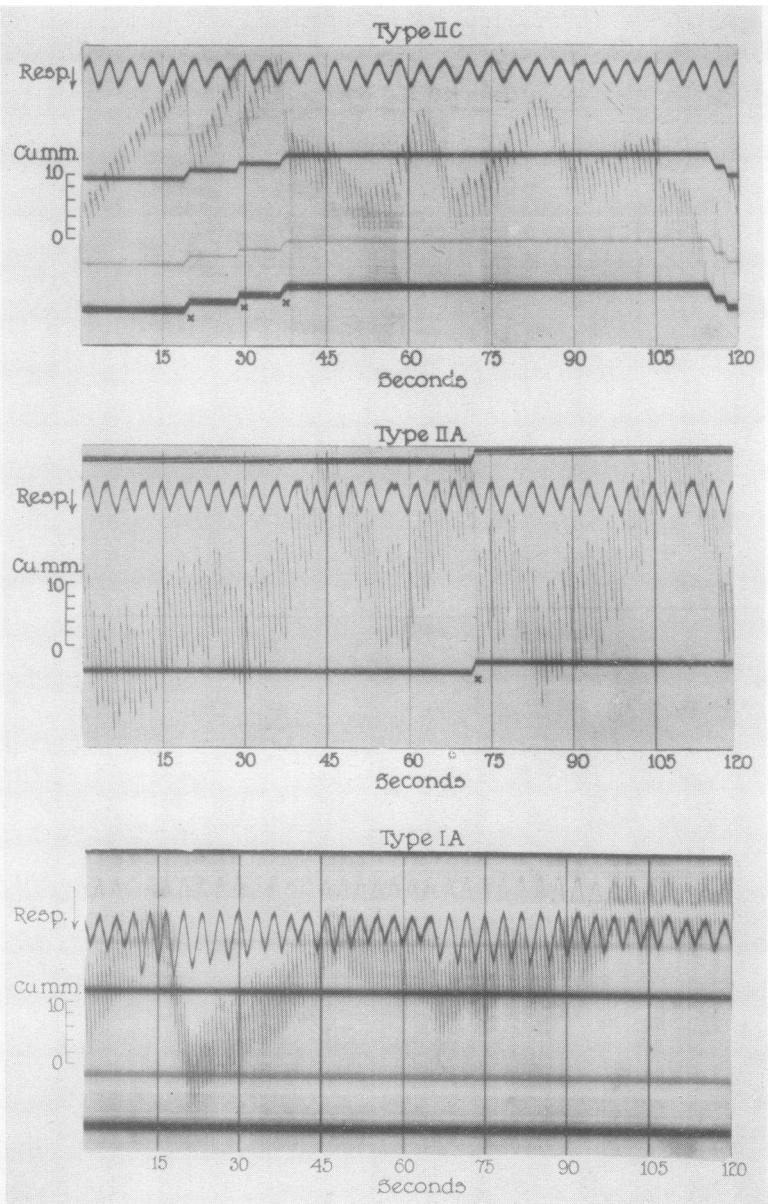

FIG. 2. ORIGINAL RECORDS ARE REPRODUCED TO ILLUSTRATE VARIOUS TYPES OF ALPHA WAVES

The records of Types II C and II A show particularly well how similar alpha waves may be combined with entirely different pulse waves. The downward direction of the arrow indicates inspiration. Changes in the position of the base-line, to keep the record in the optical field, are indicated by X.

were large, others in which they were small, and still others in which small and large ones were found at different times. The decision as to whether the pulse waves were large or small depended upon studying the whole series of records obtained from each individual. To obtain a standard for comparison, small pulse waves (2 to 4 cu. mm.) could always be obtained at the end of each record by asking the subject to inspire deeply. If the pulse waves secured at rest were

of this order of magnitude, they were classed as small; if at least 3 times this magnitude, large (9 to 12 cu. mm.). Large pulse waves were of a size comparable with those obtainable by artificial methods of producing prolonged vasodilatation. Such methods were not employed in the present study, the object having been to obtain records as free as possible from the effects of external influences.

Pulse waves which were predominantly large were called "A," those that were small "B," and those of varying size "C." With 3 types of records of pulse waves and 3 types of records of alpha waves, theoretically 9 combinations are possible. Actually, only 8 were noticed:

I A, with small alpha and large pulse waves;
I B, with small alpha and small pulse waves;
I C, with small alpha and varying pulse waves;
II A, with intermediate alpha and large pulse waves;
II B, with intermediate alpha and small pulse waves;
II C, with intermediate alpha and varying pulse waves;
III A, with large alpha and large pulse waves;
III C, with large alpha and varying pulse waves.

This list permits a choice of 3 types which are clearly distinguishable, both on inspection of the tracing and by measuring. These are I A, I B, and III C (Figures 1 and 2). Although II A, II B, and II C are distinct types, they are intermediate and cannot as readily be identified by inspection alone.

It was apparent that a person's record exhibited, during a given period, consistent characteristics. Just afterwards, he formulated his estimate of his emotional status. The suggestion lay close, as has been said, to making an attempt to explore the possibility of a relation between the two. When the records changed, the question to be answered was, "Was there a change also in his emotional status?" Unfortunately, too few subjects were studied to provide a basis for a statistical study of the results. Definite trends were however detected. When intense anxiety was reported, the plethysmographic records uniformly exhibited small alpha and small pulse waves (Type I B); contentment with its accompanying relaxation went hand in hand with small alpha waves

TABLE I

Comparison of the type of alpha and pulse waves with the dominant emotion

Subject number	Age	Date	Volume of alpha deflections	Average number of alpha deflections	Size of pulse waves	Classification	Dominant emotion	Remarks
	years		*cu. mm.*	*per minute*				
122	29	May 4, 1942	16	4.0	Varying	II C	Resentment, Sadness	Marked resentment present for 3 to 4 days. Cause unknown.
		May 22, 1942	25.7	5.0	Varying	III C	Resentment	
		June 15, 1942	18.6	5.1	Varying	III C	Resentment	
		June 25, 1942	7.6	4.7	Large	I A	Contentment	Duration—several hours.
123	38	April 23, 1942	10	6.0	Large	I A	Contentment	Duration—several hours.
		April 30, 1942	12	4.5	Small	I B	Anxiety	Sudden onset, 2 hours duration, related to necessity of giving a lecture.
		June 5, 1942	18	2.8	Large	III A	Resentment	Slight in intensity, fleeting duration, related to memory of interpersonal situations 5 yrs. previously.
124	27	April 10, 1942	32.1	6.5	Varying	III C	Anxiety	Duration about 7 days, gradual onset, related to subject's imminent marriage (on April 11, 1942).
		May 14, 1942	13.7	6.4	Large	II A	Contentment	Slight anxiety, 8 hours duration, related to sexual topic.
		May 25, 1942	9.7	7.0	Large	I A	Depression	Slight fatigue, slight general muscular tension, mild alcoholic excess previous night.
		June 1, 1942	11.0	5.0	Large	I A	Contentment	Anxiety very slight and fleeting, contentment dominant.
		June 15, 1942	14.3	5.2	Large	II A	Anxiety	Sudden onset just prior to recording, related to telephone call with no opportunity for answering.

TABLE I—*Continued*

Subject number	Age	Date	Volume of alpha deflections	Average number of alpha deflections	Size of pulse waves	Classification	Dominant emotion	Remarks
	years		*cu. mm.*	*per minute*				
125	28	April 21, 1942	10.0	4.5	Varying	I C	Contentment	Duration 6 to 7 hours.
		May 7, 1942	9.0	5.2	Small	I B	Anxiety	Duration 6 hours, sudden onset; related to major operation on father on day of recording and to rejection of subject by an important friend.
		May 12, 1942	19.8	4.0	Varying	III C	Anxiety	Father's illness, situation with his friend improved, emotion less intense than on May 7, 1942.
		May 14, 1942	23	4.3	Varying	III C	Elation	Moderate, duration 4 hours, gradually decreasing intensity related to offer of desirable job and to leaving present position.
		May 27, 1942	17.5	4.4	Varying	II C	Depression	Slight, 3 hours, related to war.
		June 5, 1942	19.9	4.4	Varying	III C	Mixed	Resentment, contentment, anxiety in slight degrees, indefinite durations and causes.
		June 15, 1942	20.6	6.4	Varying	III C	Elation	Moderate intensity, 1 hour duration, related to news of a patient's good progress (others had given poor prognosis).
		June 16, 1942	20.6	5.9	Varying	III C	Anxiety	Duration half hour, moderate intensity, related to complications in father's illness.
		June 18, 1942	18.5	5.9	Varying	III C	Resentment	Slight, duration 2 to 3 hours, related to situation with patient.
126	29	May 1, 1942	14	5.3	Large	II A	Resentment	Slight, related to a delay in the recording.
		June 2, 1942	13.1	5.5	Small	II B	Resentment	Slight, occurred during recording, cause unknown.
127	28	May 11, 1942	16	4.1	Varying	II C	Anxiety	Slight, sudden onset just before recording, cause unknown.
		June 5, 1942	20.2	6.2	Varying	III C	Depression	Slight, duration 7 hours, fatigued, diarrhea and malaise all day.
		June 18, 1942	15.8	6.0	Varying	II C	Anxiety	Slight, sudden onset during recording, related to thoughts of work.
128	30	May 29, 1942	19.5	5.3	Varying	III C	Elation	8 hours duration, moderate intensity, related to friend getting a job.
		June 19, 1942	23	4.8	Varying	III C	Resentment	Onset during test, related to his need to use time otherwise.
129	30	May 6, 1942	21.6	6.2	Varying	III C	Anxiety	Moderate intensity 10 days, gradual onset, related to approaching marriage.
		June 2, 1942	18.3	6.6	Varying	III C	Anxiety	As above.
		June 25, 1942	44.3	5.4	Varying	III C	Elation Resentment	Post marital (2 weeks) elation, moderate degree; resentment slight, with onset during recording, related to wish to be doing something else.
130	32	May 18, 1942	15.3	4.2	Varying	II C	Contentment Anxiety	Slight degrees of both, both present 5 to 10 days, causes unknown.
131	28	May 19, 1942	16.3	8.0	Small	II B	Contentment Anxiety	Both slight. Anxiety present 2 hours and related to preparation of lecture material.
		May 23, 1942	14.3	7.8	Small	II B	Anxiety	Moderate intensity, duration 4 days, related to above.
		May 26, 1942	13.0	8.3	Small	II B	Resentment Anxiety	"Resented being experimented upon," moderate intensity. Anxiety as above —lectures to start June 1, 1942.
		June 1, 1942	14.4	7.4	Varying	II C	Anxiety Elation	4 hours after first lecture; anxiety less, slight elation.
		June 9, 1942	25.3	4.8	Varying	III C	Anxiety	Slight, 6 hours, related to sexual topics.
		June 19, 1942	12.0	7.1	Large	I A	Contentment	Gradual onset, 8 hours duration.

TABLE II

Comparison of the intensity of certain emotions with type of alpha wave at time of recording

Emotion	Subject number	Date	Volume of alpha deflections	Volume of pulse waves	Average number of alpha deflections	Classification of alpha wave record	Intensity of emotion
			cu. mm.	*cu. mm.*	*per minute*		
Anxiety	127	May 11, 1942	16.0	Varying	4.1	II C	+
	127	June 18, 1942	15.8	Varying	6.0	II C	+
	129	May 6, 1942	21.6	Varying	6.2	III C	++
	131	June 9, 1942	25.3	Varying	4.8	III C	++
	124	June 15, 1942	14.3	Large	5.2	II A	++
	124	April 10, 1942	32.1	Varying	6.5	III C	+++
	125	May 12, 1942	19.8	Varying	4.0	III C	+++
	129	June 2, 1942	18.3	Varying	6.6	III C	+++
	131	May 23, 1942	14.3	Varying	7.8	II B	+++
	125	June 16, 1942	20.6	Varying	5.9	III C	++++
	125	May 7, 1942	9.0	Small	5.2	I B	++++
	123	April 30, 1942	12.0	Small	4.5	I B	++++
Resentment	123	June 5, 1942	18.0	Large	2.8	III A	+
	126	May 1, 1942	14.0	Large	5.3	II A	+
	126	June 2, 1942	13.1	Small	5.5	II B	+
	128	June 19, 1942	23.0	Varying	4.8	III C	++
	125	June 18, 1942	18.5	Varying	5.9	III C	++
	122	June 15, 1942	18.6	Varying	5.1	III C	++
	122	May 22, 1942	25.7	Varying	5.0	III C	++
Elation	125	May 14, 1942	23.0	Varying	4.3	III C	++
	125	June 15, 1942	20.6	Varying	6.4	III C	++
	128	May 29, 1942	19.5	Varying	5.3	III C	++
Depression	125	May 27, 1942	17.5	Varying	4.4	II C	+
	124	May 25, 1942	11.0	Large	5.0	I A	+
	127	June 5, 1942	20.2	Varying	6.2	III C	++
Contentment	122	June 25, 1942	7.6	Large	4.7	I A	++
	124	June 1, 1942	11.0	Large	5.0	I A	++
	125	April 21, 1942	10.0	Varying	4.5	I C	++
	131	June 19, 1942	12.0	Large	7.1	I A	+++
	123	April 23, 1942	10.0	Large	6.0	I A	+++

and large pulse waves (Type I A). There were 2 variants; one with intermediate alpha and large pulse waves (Type II A) and one with small alpha and varying pulse waves (Type I C). The former was borderline, the alpha waves being only 0.7 cu. mm. larger than the usual I A alpha waves; the other, also borderline, exhibited varying instead of uniformly large pulse waves. Anxiety of moderate degree, elation, and resentment were commonly associated with records having large alpha waves and varying pulse waves (Type III C) (Tables I and II).

These 3 groups were distinct. Plethysmographic records of the intermediate types (II A, II B, II C, III A) were associated with reports of slight resentment or slight anxiety, sadness, or a combination of various emotions, none of which was dominant. No uniformity was present in the records of the subjects reporting depression. Of these 3 records, one was Type II C, another III C, and the third, I A. At no time was a change in the type of the alpha wave-pulse wave configuration noticed in any of the groups during the course of a single observation, nor was a change in emotional status.

In 2 subjects, records were made during sleep, at short intervals throughout an entire night. Sleep was continuous and not restless. Alpha deflections occurred throughout the night; unfortunately, neither subject remembered any dreams so that a comparison of the records with their emotional state was impossible. In point of fact, records obtained during sleep resembled those obtained just before and after. Their emotional status before and after likewise remained unchanged. They were in a state of moderate anxiety.

DISCUSSION

Comparison of plethysmographic records with reports of concomitant emotional states has pro-

vided a new insight into one factor at least that can influence the type of alpha and pulse waves. There are undoubtedly other influences beside emotional status which bring on change, though this one is strong. How it operates is unknown. Conceivably, Type I A waves (small alpha, large pulse) depend upon minimal sympathetic outflow providing little stimulus for the development of prominent alpha waves or for hindering the maximal expansion of the small blood vessels. Such records are not infrequent in relaxed and contented subjects. When sympathetic outflow is maximal, it is probable that small blood vessels can neither expand fully when the heart beats nor dilate to permit the development of alpha waves. I B records must therefore occur (small alpha, small pulse waves). Such records would be anticipated and actually do occur during anxiety. When the sympathetic outflow is moderate, conceivably the result of altering swings in tone, the basis (alternate constriction and dilatation) exists for those states which yield prominent alpha waves and variable, sometimes small, sometimes large, pulse waves. They are found when the emotions reflect less anxiety. Whether progressive increase in sympathetic outflow actually causes the change from small (slight stimulus) to large (moderate stimulus) and again to small (intense stimulus) alpha waves cannot now, of course, be completely established, but such an explanation would account for those changes in the records which appear with changing emotional states.

Such situations are recognized as being associated with variable activity of the autonomic nervous system. An important; perhaps conclusive, reason for believing that alpha waves reflect activity of the sympathetic nervous system results from a study of the effects of cutting the sympathetic nerves. Alpha waves then disappear and a great increase in size of pulse waves takes place. The result is an approximation to the Type I A record (small alpha and large pulse waves), characteristic of a normal subject's period of contentment and relaxation (presumably with minimal sympathetic outflow). These statements are also supported by a review of the effects produced when spinal anesthesia is employed to interrupt impulses along the sympathetic nerves to the lower extremities. Patients presenting large alpha and variable pulse waves (Type III C), in both toes and fingers before anesthesia, show, within 2 minutes after anesthetization, progressive change to small alpha and large pulse waves (Type I A), that is to say, marked vasodilatation in the *toes*. At the same time, the record of the *fingers* changes to small alpha and small pulse waves (Type I B), that is to say, marked vasoconstriction. These concomitant changes develop in the absence of any measured change in pulse rate or blood pressure. They have been explained as an effect, possibly compensatory, mediated by increased sympathetic outflow to one vascular bed (as evidenced in the finger) to offset decreased sympathetic flow to another vascular bed (as evidenced in the toes) (*7*).

No attempt has been made through the analysis of plethysmographic records to use such records as indicative of emotional states. A generalization may turn out to be correct, namely, that the pattern of a record (alpha and pulse wave) is expressive of a given emotional state.

The conclusion that persons of differing psychologic types are likely to exhibit characteristic pulse and alpha waves is correct. That is what these studies likewise show. It is but another form of evidence suggesting the "togetherness" of the organism. Such a type—such a physiology. Persons, not being unvarying machines, undergo alterations in mood. Then functions of their bodies, many of them, no doubt respond. That is what has now been found in the waves originating in their blood vessels. Other observers before us have noticed a correlation between measurable physiological functions and emotional states. Diethelm, Milhorat, and Small (8) in particular noticed that sadness and elation (as distinct from these same emotions combined with anxiety or resentment) showed no increase in the white cell count of the blood, whereas in states of acute fear and panic, persistent anxiety and tension, anger, or resentment, there was leukocytosis.

CONCLUSION

Spontaneous variations in the volume of the finger tips are classifiable in 3 major types and 5 lesser ones. The 3 major types are (*1*) a combination of small alpha waves with large pulse waves (Type I A); (*2*) small alpha waves with small pulse waves (Type I B); and (*3*) large

alpha waves with varying size of pulse waves (Type III C).

Individual subjects at rest, free from recognizable external stimuli and not required to carry on intellectual activity, have exhibited changing records. This kind of variability has been found to go closely hand in hand with changes in emotional status. Certain records (Type I A) were obtained only from subjects in a state fully relaxed and contented. Certain others (Type I B) occurred when anxiety was dominant. With less anxiety or with elation or resentment, Type III C records were obtained. With depression, no uniform alpha-pulse wave pattern was observed. Slight resentment or slight anxiety or a combination of various emotions, none of which was dominant, occurred with intermediate types of records. On the assumption that changes in the degree of activity of the autonomic nervous system parallel changes in emotional status, an explanation is proposed for the changes based on changes in the autonomic nervous system, the results of which have been observed in alpha and in pulse waves and in combinations of the two.

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