RELATION OF BODILY TENSION TO ELECTRICAL RESISTANCE

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PROBLEM

THE GENERAL problem of this experiment was to compare the electrical resistance of the subject during relaxation with his resistance during bodily tension. The electrical resistance of the human body has been studied by many investigators under various conditions. It has been studied with reference to the activity of the sweat glands by: Darrow (1), Einthoven and Roos '(3), Georgi (4), Markbreiter (6), Waller (11), and Wells and Forbes (14). It has been studied with reference to circulation by: Jung and Peterson (9), Sidis and Nelson (9), Waller (11). Feri (5), Jung (5), Darrow (1), Prideaux (7), Sidis and Kalmus (8), Tarchanoff (5), Veraguth (5), and Wechsler (13) have studied it with reference to mechanical chemical and electrical stimulations. No one, so far as the writer has been able to ascertain, has made any thoroughgoing investigation of the relation existing between bodily tension and electrical resistance. This relationship should not be neglected, for if it is discovered that the electrical resistance does vary with bodily tension, it will be necessary to take this fact into consideration in performing experiments with the psychogalvanic reflex and in interpreting the experiments hitherto performed.

APPARATUS

The electrodes used in this experiment were made of zinc, and were about two centimeters long and a centimeter wide. These electrodes were covered with kaolin paste and an extremely weak solution of zinc sulphate. They were bandaged to the hand. The electrodes were connected directly to Leads I and II of Hindle's Electrocardiograph.

The regular hook-up of the Electrocardiograph was used with two modifications; Lead III was never employed; and the Jacquet Chronograph was substituted as a time marker for the tuning fork supplied with the instrument. The photographic attachment was used throughout.

PROCEDURE

The subject lay on a couch with either one or both hands attached to two electrodes. For relaxation the subject was asked simply to rest and if possible to sleep. The latter did not occur with most of the subjects because there were only two relaxation periods of ten minutes each in an experimental period to forty minutes. For tension, the subject was asked (1) to keep all the muscles of his body as tense as possible for ten minutes, (2) to squeeze a dynamometer as tightly as possible for ten minutes, or (3) to work some multiplication problems mentally. Under the first condition (hereafter called Series I) one electrode was attached to the palm of each hand. Under the second and third conditions (hereafter called Series II and III, respectively) the electrodes were attached to one hand. If the subject were right-handed, the electrodes were attached to the left hand, and vice versa. The experiment was conducted as follows: The electrodes were attached to the hands. The lights were turned out. The subject was told to relax for ten minutes. At the end of the ten minute period he was asked to do either (1), (2), or (3) listed above. Then he was asked to relax for ten minutes more; and for a final ten minutes he was asked to repeat the second condition.

At the start of each experimental period, the tension of the string in the electrocardiograph was adjusted so as to give exactly one centimeter deflection for every millivolt of current. In this way it is possible to compare the deflection caused by the subject with the standand amount and to determine exactly the resistance of the subject by the use of Ohm's law. Ohm's law states:

$$\frac{E}{I \times R} = \text{a constant, in the equation}$$

$$\frac{E}{I(R+r)} = \frac{Es}{Is(Rs+rs)}$$

Es = the standardizing E. M. F.
Rs = the standardizing resistance
Is = the current (deflection) with the standard R and E (the deflection is proportional to the current passing through the string and the deflection in centimeters is in each case substituted for I)*
rs = the resistance of the string
E = the potential under the conditions of measurement
R = the resistance under the conditions of measurement
I = the deflection under the conditions of measurement

In our problem we have the following values:

Es = one millivolt
Rs = 40,000 ohms
rs = 3,200 ohms
E = one millivolt
I = one centimeter

This leaves one unknown quantity R which can be readily calculated. In each series, the states of relaxation and tension are alternated; that is, each period of relaxation is followed by a period of tension and vice versa. This procedure was followed in order to eliminate to some extent the effect of polarization.

Three times a minute one millivolt of current was shot into the circuit. The deflections caused by the millivolt were measured. This measure was then inserted in the equation and the resistance of the subject then computed. Since the millivolt was introduced into the circuit three times a minute, on the average thirty measurements were obtained for each subject during each period. Each subject was used only for one forty minute period.

SERIES I

The electrodes were attached to the palm of each hand in this series. For tension the subject was asked to contract and hold as rigid as possible all the voluntary muscles, especially those of the legs and arms, but to take care not to squeeze the electrodes. The tension period was of ten minute duration and it was followed by a ten minute relaxation period. For each subject two relaxation and two tension periods were obtained.

*See Darrow, C. W. "Sensory, Secretory and Electrical Changes in the Skin Following Bodily Excitation," Journal of Experimental Psychology, X, 3, June, 1927.

In Table Ia the averages and standard deviations are correct only to the third place. Since a difference of a single ohm is of no significance, it was believed to be useless to use any finer measure in obtaining the standard deviation. In the first column the subjects are indicated by Roman numerals. In the second column is the average of the ohmic resistance during the first period of relaxation; in the third column is the standard deviation of this average; in the fourth column is the average of the period of tension followed by the standard deviation. The sixth column contains the difference between the average relaxation and the average in tension (D. A.). The standard error is placed in the seventh column as an indication of the reliability of the difference. Columns eight to fourteen represent in the same way the data obtained during the third and fourth ten-minute periods of experimentation.

While each of the averages given in the table are based upon at least 30 measurements we are not interested in the particular amounts of resistance as much as in the fact that the resistance in relaxation is different from the resistance in tension. To bring this out more clearly Table Ib is given. In Table Ib "g" indicates that the electrical resistance is greater during relaxation than during tension; "l" indicates that the resistance is lower during relaxation. The capital case signifies that the difference is thoroughly reliable; that is, the difference is at least four times the standard deviation of difference.

Summarizing the table, we find that out of 26 ten minute periods:

a. The average electrical resistance is greater during relaxation in 25 periods.

b. The difference in 18 periods is thoroughly reliable.

We may conclude therefore that there is a marked tendency for electrical resistance to be greater during general relaxation than during general contracture.

TABLE Ia, SERIES I

Electrodes attached to both hands

1	2	3	4	5	6	7	8	9	10	11	12	13
Subj	Relax	S.D.	Tens	S.D.	D.A.	S.D.A.	Relax	S.D.	Tens	S.D.	D.A.	S.D.A.
I	47181	8766	28943	4485	18138	1652	68740	6697	36164	1174	26576	246
II	57400	5439	26250	00	31150	992	53613	5290	35606	3232	18013	325
III	28433	4362	39635	506	–11202	802	**		24760	689	*3673	113
IV	64819	6551	38111	661	26708	1201	68910	5999	**	**	**	
V	42790	5834	21058	1337	21638	1095	**		**			
VI	41721	1949	17778	1206	23193	419	52050	00	22992	3694	30158	213
VII	72785	3244	29139	2565	43546	754	67100	7125	56750	798	10350	4171
VIII	93371	5350	21985	2430	72386	453	95200	6813	23406	998	71794	4299
IX	98100	5867	77600	3459	20500	1244	104000	100000	92266	2346	11734	428
X	36368	2772	33921	1983	2347	616	37300	1559	29739	2080	7561	453
XI	34631	4183	19150	137	15481	763	23170	0000	21985	530	1185	957
XII	53475	5695	40970	2709	15505	5875	46025	2695	32892	1777	13133	589
XIII	23792	1320	23170	0000	622	240	29000	1221	30085	2141	1085	450
XIV	64612	3243	14800	0000	49812	592	42587	4758	24315	9480	18275	613

Explanation as to symbols used in the preceding table: *Difference of average between 2 and 10; **Values were not obtained due to some defect in the apparatus.

TABLE Ib, SUMMARY OF TABLE Ia

Subj	Columns 2, 4	Columns 8, 10	Subj	Columns 2, 4	Columns 8, 10
I	G	G	VIII	G	G
II	G	G	IX	G	g
III	L	G	X	g	G
IV	G		XI	G	g
V	G		XII	g	G
VI	G	G	XIII	g	g
VII	G	g	XIV	G	G

G indicates that the resistance is greater during relaxation than during tension and that the difference is thoroughly reliable.

g indicates that the resistance is greater during relaxation than during tension.

L indicates that the resistance is less during relaxation than during tension and that the difference is thoroughly reliable.

SERIES II

In this series the subject squeezed the dynamometer with his free hand during the tension period. He was asked to squeeze it as hard as he could, and yet not to such an extent that he would be unable to hold it for ten minutes. Of course there were minor fluctuations in the intensity with which the dynamometer was held; in fact such fluctuations may be responsible for the slight discrepancy obtained in some of our results.

In this series we had eleven subjects, and the results from each of which are given in Table IIa. The method of obtaining the average resistance for the two periods is the same as the method used in Series I. Our results, however, are slightly different from those obtained in the former series.

With one or two exceptions, the resistance is never as great as that obtained in the first Series. This is, no doubt, due to the way in which the electrodes were attached. The difference between the resistance in relaxation and in tension is not as great in this series as in the other. Probably this result can be explained by the fact that in this series the subject was asked simply to squeeze the dynamometer or to contract primarily the muscles of one arm, whereas in the former series he was asked to contract and hold contracted as many muscles as possible. Table IIb gives a summary of the results of Table IIa.

From these tables we note that out of 21 pairs of averages:

a. 18 show that the electrical resistance is greater during relaxation than during tension.

b. 15 out of 18 pairs of averages give differences that are at least four times as great as the standard deviation, and hence are to be considered as thoroughly reliable.

c. 3 pairs of averages indicate that the resistance is greater during tension than during relaxation.

d. The differences between average resistance during relaxations and tension, for those pairs in which the former are greater than the latter, are more than four times as great as the standard deviation, and hence may be regarded as reliable.

TABLE IIa, SERIES 2

Electrodes attached to one hand

1	2	3	4	5	6	7	8	9	10	11	12	13
Subj	Relax	S.D.	Tens	S.D.	D.A.	S.D.A.	Relax	S.D.	Tens	S.D.	D A.	S.D.A.
I	26140	396	25876	1216	264	7021	56237	4603	52050	00	4187	85
II	63216	4325	52050	00	11166	249	95000	3555	68800	00	26250	649
III	80533	9089	55400	3493	35133	1776	64612	4039	52050	00	12562	737
IV	8797	634	12614	2580	–3817	483	13410	00	12770	5244	640	956
V	11186	1523	18406	3728	–7220	755	**		**			
VI	39664	964	27611	1180	2053	278	52050	00	49640	435	2410	79
VII	44800	1074	31563	208	13237	388	23339	3168	24260	3762	1921	896
VIII	37120	2037	30711	344	6409	372	54400	7420	36933	168	27467	1356
IX	34435	7712	14438	7871	19997	2011	21985	3251	**		*7547	1874
X	80533	1777	82800	1610	–2267	438	104000	00	86400	596	17600	130
XI	25070	498	17025	5244	8045	974	36400	7712	23940	3168	12461	1521

*Difference between 4 and 8

**No values obtained due to some defect in apparatus.

TABLE IIb, SUMMARY OF TABLE IIa

Subj	Columns 2, 4	Columns 8, 10	Subj	Columns 2, 4	Columns 8, 10
I	g	G	VII	G	g
II	G	G	VIII	G	G
III	G	G	IX	G	G
IV	L	g	X	L	G
V	L		XI	G	G
VI	G	G			

G indicates that the resistance of the relaxation state is greater than the resistance of the tension state and that the difference is thoroughly reliable.

g indicates that the resistance of the relaxation state is greater than the resistance of the tension state.

L indicates that the resistance of the relaxation state is less than the resistance of the tension state and is thoroughly reliable.

SERIES III

This series involved silent multiplication as one of the conditions. The object was to see how electrical resistance during so-called mental work differed from that during so-called muscular work. It is entirely out of the question to define here "mental" and "muscular" work; but we do wish to point out some of their similarities and differences in connection with our specific problem. Both of them called for the exercise of the voluntary muscles. Perhaps in the "mental" task the locus of muscular activity differed from the locus of activity in the "muscular" work. Both the "mental" and "muscular" work called for an exercise of volitional judgment. The subject must will to do both. The problem of "muscular" work, however, was largely to maintain the status quo. It was spastic effort. The subject endeavored to keep the muscles rigidly contracted either in the body as a whole or in a particular segment of the body. The task we used the represent "mental" work called fcr a changing bodily state; that is, the individual must perform several operations to accomplish the task. It was not static.

The subject in this series was given two place figures to multiply by each other during the alternate ten minutes of an experimental period of forty minutes. The subject multiplied silently and then gave an oral answer. As soon as he gave an answer to one problem he was given another. No attempt was made to check the correctness of the answer given. The results are given in Table IIIa, and summarized in Table IIIb.

In 14 pairs of averages from seven subjects there is only one that indicates that the electrical resistance is greater during mental multiplication than during general relaxation. The differences in averages of all the instances are thoroughly reliable; that is, the difference is four times the standard deviation.

TABLE IIIa, SERIES 3

Electrodes attached to one Hand—Mental Multiplication

1	2	3	4	5	6	7	8	9	10	11	12	13
Subj	Relax	S.D.	Tens	S.D.	D A.	S.D.A.	Relax	S.D.	Tens	S.D.	D.A.	S.D.A.
I	86400	7871	68800	00	17600	1436	57633	3626	21016	1394	36617	708
II	83400	7871	61600	5577	24800	175	104000	00	80533	4326	23470	3103
III	57633	3626	21016	1394	36617	2237	63216	3614	***		*42200	1768
IV	74950	9682	33567	5019	41383	1787	46025	2695	***		*12458	491
V	68800	00	80533	7417	–11733	1353	92233	4413	77600	6816	14433	1481
VI	104000	00	26473	3737	77527	628	68800	00	***		**42327	00
VII	92866	7417	64722	5452	28144	1353	104000	00	68800	00	35200	00

*Difference in averages between 4 and 8
**Difference in averages between 2 and 8
***No values obtained due to some defect in apparatus.

TABLE IIIb, SUMMARY OF TABLE IIIa

Subjects	Columns 2, 4	Columns 8, 10	Subjects	Columns 2, 4	Columns 8, 10
I	G	G	V	L	G
II	G	G	VI	G	G
III	G	G	VII	G	G
IV	G	G			

G indicates that the resistance of the relaxation state is greater than the resistance of the tension state and that the difference is thoroughly reliable.

g indicates that the resistance of the relaxation state is greater than the resistance of the tension state.

L indicates that the resistance of the relaxation state is less than the resistance of the tension state and that the difference is thoroughly reliable.

Table IIIa with reference to Tables Ia and IIa suggests that "mental" work causes a greater decrease in electrical resistance than general or local contraction. A valid difference, however, cannot be thoroughly established from our experiments because the subjects were not the same, and the electrodes were attached in different places.

CONCLUSION

In general it has been found that there is a higher electrical resistance in relaxation than in tension, and that general contracture differs more from general relaxation than does local contracture. These facts are supported by a comparison of general muscular relaxation (1) with general muscular contraction, (2) with localized muscular contraction, and (3) with bodily conditions during silent multiplication.

The importance of a study of this sort is seen when one notes the numerous experimenters who have measured the galvanic response in terms of ohms resistance. To illustrate, we may consider Smith's (10) investigation. He balanced the subject's resistance in a Wheatstone bridge. As soon as the resistance of the subject changed, the bridge would be thrown out of balance and the galvanic string would deflect. It is conceivable that the deflection of the string, which often has been called the galvanic response, may be due to a change of bodily resistance, due to various organic changes. Moreover such effect may be produced not by particular stimuli, but simply by the situation in general.

The same criticism can be applied to a large number of experiments: Feri, Jung, Sidis and Kalmus, Veraguth, and Waller. Of course, it may be that the state of relaxation did not vary during their experiments; but they at least took no cognizance of it.

By an elaboration of the method, it may be possible to get a measure of relaxation or sleep. It is possible too that this method will throw some light on the relation of the so-called mental states to so-called muscular states.

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