J Y V Ä S K Y L Ä N   Y L I O P I S T O N

KANSANTERVEYDEN LAITOKSEN JULKAISUJA

U N I V E R S I T Y   O F   J Y V Ä S K Y L Ä

DEPARTMENT OF PUBLIC HEALTH PUBLICATIONS

No 14   1972

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Urinary excretion of catecholamines during a psychomotor choice reaction test before and after physical conditioning

This research has been supported by a grant from the Finnish Research Council for Physical Education and Sports, Ministry of Education, Finland.

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URN:ISBN: 978-951-39-9043-5
ISBN 978-951-39-9043-5 (PDF)
ISSN 0357-4563

Jyväskylän yliopisto, 2022

Abstract

Sarviharju, P.J. and E. Mattila: Urinary excretion of catecholamines in a psychomotor choice reaction test before and after physical conditioning

Urinary excretion of noradrenaline and adrenaline and the performance of 12 volunteer male students were determined during a highly motivated competition in a 45 minute psychomotor choice reaction test. The measurements were repeated after a nine-week period of regular endurance conditioning with 6 of the subjects. In comparison with the control situations the urinary excretion of catecholamines increased significantly in both measurements ($p < .001$). The prevalence of mental tension reflected in a significantly decreased ratio of noradrenaline to adrenaline ($p < .05 - .01$). No significant adaptation was found. A tendency was found in the high excretion group having less errors during the CRT than the low excretion group. After the training no significant difference in the performance during CRT or in the urinary excretion of catecholamines was noticed between the trained and the control group.

The close relationship of the augmented sympathoadrenal activity and the increased urinary excretion of adrenaline and/or noradrenaline due to the various kinds of stimuli of psychological origin is documented by numerous authors and recently reviewed, for example, by Mason (1968). The control on the sympathoadrenal mechanism via the central nervous system and the role of catecholamines on that activity of regulation is largely obscure. It is suggested that the reticular formation and its hypothalamodiencephalic portion has a central role in the regulation of the various functions of psychosomatic origin and the catecholamines are a significant transmitter in those mechanisms (Söderberg, 1962; Dell, 1963). It has been suggested that catecholamines will control the psychomotor functions when producing an effect on the hypothalamic portions via blood or that the reticular formation has its own adrenergic mechanism of excretion (Carlson, et. al., 1960; Dell, 1960).

As generally accepted mental stress, exhilarating or aggressive reactions and those responsible for blood pressure and temperature homeostasis will increase the excretion of noradrenaline and the types of emotional stress mainly characterized by apprehension, anxiety, pain or general discomfort are regularly accompanied by an increase in the adrenaline excretion (Euler, 1964)

The role of the adrenomedullary system on the effectiveness of behaviour has been studied while measuring the urinary excretion of catecholamines before and during a loading situation and while infusing adrenaline and measuring its effect on the performance. Both understimulation and over-stimulation during sensorimotor tests have been produced an increase of adrenaline and noradrenaline release (Frankenhaeuser, et. al.,1970).

The subjects with a high excretion will generally succeed better in a perceptual-conflict test and in the choice of reactions than those with a low excretion of catecholamines (e.g. Patkai and Hagdahl, 1967; Frankenhaeuser, et. al., 1968: Frankenhaeuser and Rissler, 1969). These results are quite consistent with some observations in studies, where adrenaline has been infused during a performance test. In a test which demanded concentration Frankenhaeuser and Jaerpe (1963) found an increased performance as a function of infused adrenaline of 0.05-0.20 μg per kg of body weight per minute. On the other hand, larger doses of adrenaline have decreased the performance in memory, reaction time and durability in choice reaction tests (Euler, 1966).

Obviously the catecholamine reactions are coupled with some personality characteristics. Depressive subjects have responded to psychic stress with a relatively smaller excretion of adrenaline than the others (Frankenhaeuser and Patkai, 1965). Roessler, et al., (1967) found that during university examinations the students with a low ego strength responded with a depressed excretion of catecholamines and the students with a high ego strength with an increased excretion. Furthermore, it is suggested that the excretion of catecholamines during stress is related to stress tolerance (Levi, 1963).

On the other hand an over-all concept can be visualized by which a certain kind of physical training will increase the parasympathetic tone or decrease the sympathetic one during rest (Nöcker, 1971). Some evidence suggests this such as the observation that an intensive physical training decreases the urinary excretion of VMA (Adam, et al., 1968) and of adrenaline (Sarviharju et al., 1971). However, there are only a few systematic attempts to study the effects of regular physical training on the sympathoadrenal functions.

The purpose of the present study was to investigate the activity of the sympathoadrenal system by measuring the urinary excretion rates of highly motivated subjects during a psychomotor choice reaction test and to study the effect of physical training on those endocrine functions; both as a part of a large project.

METHODS

Subjects

Altogether healthy, 12 volunteer, male students served as subjects. The aim was to form, with the matched pairs method, one control and one test group, as similar as possible, on the basis of their submaximal working heart rate. Of various reasons toward the end of the selection and during the experiment this matching was quite distorted and so we had relatively heterogenous groups. Two of the pairs had been subjects in the first part of the study during the same year (Sarviharju, 1972). The descriptive data of all the subjects are presented in Table I.

Loading procedure

The psychomotor loading was achieved with a continous choice reaction test (CRT) during 45 minutes. The subjects were inctructed and had a chance to operate with the apparatus in a standardized manner for 15 minutes two days before the actual test, and they were motivated with several monetary rewards. Immediately before the test they were once again instructed by a magnetophone. The subjects were sitting by the apparatus [1] (Figure I) in a quiet room and had to cope with three separate tasks simultaneously. In the first one a group of 6, 7 or 8 yellow lights (Light 1) appeared on a red background on the panel randomly in series of 25 times. Each series included 8 times a group of 7 lights, which was the only one to be reacted to by pressing with the right hand a lever to left or right according to the direction of an arrow sign appearing every time beside the group of lights.

A too wide movement was indicated automatically to the subjects as a red flash of light in the middle of the panel. Besides this during the series a reaction was expected to a red light (Light 2), which was situated straight ahead, by

1) The apparatus was constructed at the Department of Psychology, University of Jyväskylä. The auxiliary devices to the original apparatus were constructed according the motive of the author.

pressing with the right hand the other lever beside the panel. If the subject did not press this lever during 5 seconds after the signal, a loud alarm signal was switched on automatically and stayed on until the subject pressed the lever.

At the same time the subjects had to cope with a third task by pressing the left or right foot pedal when a sound signal came to the left or right earphone respectively. The signals coming simultaneously to both earphones were not to be reacted to. There were 16 sound signals to be reacted to in a series of 25 signals.

The subjects had to react to all the signals a quickly as possible. The reaction was noted by the subject via the lights. All the 25 signals in a series appeared at intervals of 1.2 seconds. The electric counters recorded continuously the numbers of signals, right and wrong reactions and the cumulative reaction time. All the right reactions were taken as plus-points and the wrong ones as minus-points. The reaction time in seconds was used as the minus-points such a way, that the maximum in the reactions to the Light 1 and sound signals was 3 points, i.e., 3 seconds. In the reaction to Light 2 there was no maximum. The CRT was done before and after the nine weeks period of regular physical exercise.

Endurance training

The test subjects exercised on a bicycle ergometer five days a week, 30-60 minutes at a time, under the supervision of the investigators. The pedaling time was lenghtened progressively and equally for each subject during the nine weeks' period of training. The work load was increased, individually for each subject, in order to keep the heart rate during the exercise at 160-170 beats/min. All kinds of physical exercise besides the training program were allowed to the test subjects. The heart rates were recorded by an electrocardiograph Mingograph 24 B.

The control subjects were not allowed to participate in any physical exercise but in some cases they were asked to continue their previous habits of physical activity. All the subjects had an exercise diary and their physical activity could roughly be estimated on that basis.

The standardization of procedures

The subjects were not allowed to participate in any physical exercise the day before the tests. The evening before they had to retire at 10 p.m. From that moment they were forbidden to eat, drink or smoke before the tests were over. This prohibition was supervised by the investigators since the reporting of the subjects in the laboratory at 5.30 a.m. The subjects drunk 400 ml of water in the laboratory.

Collection of samples

Ten ml of blood from the antecubital vein was taken twenty minutes before the start of the CRT and five minutes after the test. The analysis of these samples is not reported here. The urine during relative rest on a control day was collected between 6 and 9 a.m., and during the loading it was done at a three hour period between 5.45 a.m. and 3.10 p.m. The collection period of the loading sample ended one hour and fifty minutes after the end of the CRT.

In order to bring about an adequate urine output the subjects were to drink 400 ml of water before each period of collection. In most cases the collection periods before and during the CRT were not diurnally equal due to the need to step up the CRT. Because of the pairs in this gradation, one test subject and one control subject in each pair, the average time of day when the collection was done was equal in both groups. With the exception of one case the collection time was the same for every subject in the measurement before the training period and after it.

Biochemical methods

Free catecholamines in the urine were determined by the fluorimetric method of Euler and Lishajko (1961) by absorbing them onto alumina in pH 8.3, eluating with acetic acid and oxidizing with potassium ferricyanide in pH 6.2 to adrenochromes and transforming them into fluorescent trihydroxyindoles with alkalines. The intensity of fluorescence was measured with a Perkin-Elmer MPF-2A fluorescence spectrofotometer with an activation wave length of 396 and 440 nm and an emission wave length of 510 nm.

Statistical analysis

The effect of loading in the groups was analyzed by the Student's t-test for correlated means. The same method was used when testing the change in the steady state working heart rates during the training period. The t-test was used also when checking the difference between the groups of varying pattern in the catecholamine response during the choice reaction test. The difference between the groups after the training was tested with analysis of covariance. The pre-treatment values were used as covariates. The logarithms of the primary values were used for the analysis.

RESULTS

During the choice reaction test the average urinary excretion of adrenaline (A) was in the control group from 2.4 to 4.5 and in the test group from 5.3 to 4.5 times greater than before the CRT. The respective coefficients for noradrenaline (NA) excretion were from 1.6 to 1.5 and from 1.5 to 1.6 (Table III, Figures 2-3). Except the noradrenaline excretion in the control group the differences are significant in every case ($p < .01$). The total mean excretion of both adrenaline and noradrenaline during the CRT increased highly significantly ($p < .001$) both before and after the training period (Table III).

Before the training the mean ratio of noradrenaline and adrenaline (NA/A) during loading decreased almost significantly ($p < .05$) in the test group but not in the control group (Table III). After the training the decrease was significant ($p < .05 - .02$) in both groups. In the total means this decrease was significant before the training ($p < .05$) and after it ($p < .01$).

To find out the relations of the performance and the excretion of catecholamines the subjects were grouped as to the excretion of catecholamines to a high and low excretion group via the median. The performances, as indicated by the errors, are presented in Figures 4-8. With reference to the excretion pattern the groups of high and low excretion of adrenaline and noradrenaline did not differ significantly in their performance in spite of algebraically more errors in the high excretion group (Figure 4). Similarly the performance differences in the hand movement errors, the high excretion group having a smaller amount of errors than the low excretion group, are not statistically significant (Figure 5). In the foot movement errors the difference is reversed, but not significant, either (Figure 6). The consistency prevailing in the former cases is prominent even among the NA-groups as to the unreactiveness to the light stimuli (Figure 7),the high excretion group having a smaller but not a significantly greater amount of errors than the low excretion group. As regard to the A-groups in this unreactiveness the results are no more consistent (Figure 7). On the other hand in all the cases the unreactiveness to the sound signals is more prominent, but not to a significant extent in the high excretion groups (Figure 8).

During the training period the steady state heart rate during the work of 6 minutes 1200 kpm/min on a bicycle ergometer (Table II) decreased from 151.3 $\pm$ 19.44 S.D. to 133.2 $\pm$ 13.60 S.D. in the trained group ($p < .001$) and from 161.2 $\pm$ 9.75 S.D. to 153.8 $\pm$ 15.23 S.D. in the control group. The last change is not statistically significant. The changes between the groups differed significantly ($p < .02$).

The test subjects excreted both during the relative rest and the CRT more noradrenaline ($p < .05$), and their ratio of NA and A (NA/A) was greater ($p < .01$). No other significant differences could be seen before the training, and none after it. There seems to be a tendency for the two catecholamine excretions to be lower during the training period in the trained group and not in the control one (Table III). However, no significant differences were found when the difference between the groups after the training was tested with analysis of covariance with log-transformations in the primary values and the pre-training values as covariates.

During the CRT after the training five from the six subjects in the trained group had a lower excretion of both adrenaline and noradrenaline and one subject had a higher one than before the training (Figures 9-10). In the control group three subjects had a lower and three subjects a higher excretion. A similar tendency can be seen in the excretion of noradrenaline during relative rest (Figure 12).

DISCUSSION

The increasing effect of the choice reaction test on the urinary excretion of catecholamines and especially on that of adrenaline was clearly demonsrated. At least the increase in the adrenaline excretion was obviously a result from a mental tension due to a prolonged concentration in a very demanding psychomotor task to which the subjects were highly motivated. Some amount of the increased muscular tension besides the normal movements concerned could also result in the increased excretion of noradrenaline. An obvious factor uncontrolled was the effect of the diurnal variation, in particular on the adrenaline excretion known to be relevant (e.g. Levi, 1967).

However, the average difference in the diurnal time of the urine collection between the control and CRT situations was only about three hours. Furthermore there were not found any significant diurnal change in the excretion of catecholamines in an experimental situation analogous to the present one

(Sarviharju, et al., 1971). Consequently the majority of the increase in question is suggested to be due to the CRT-effect.

This effect is consistent with some previous data during similar kind of tests (e.g. Frankenhaeuser et al., 1968, 1970). The present values of excretion during the CRT were quite high as compared to some previous ones (e.g. Frankenhaeuser, et al., 1968). These authors found an adrenaline increase averaging from 3.3 ng/min to 5.4 ng/min and the noradrenaline from 18.7 ng/min to 19.5 ng/min in a phasic loading of 90 minutes. It is supposed herein that the high excretion group would cope better with the CRT than the low excretion group. We were not able to demonstrate significant differences consistent with this suggestion. The algebraic difference in the hand movements was in accordance with this suggestion and in the foot movements contradictory. Possibly this refers to the difficulties to control the sound signal task by the subjects concentrating very hard on the other tasks and consenquently excreting more catecholamines.

The positive correlation between catecholamine excretion and performance efficiency has been found in situations characterized by a relatively low or moderate degree of arousal. The present results would tend to agree with the suggestions that in view of the inverted-U relationship which is generally found between behavioural efficiency and arousal level, the positive relation will not hold in situations which induce a high arousal level (Frankenhaeuser 1971). This is supported by the previous data of Frankenhaeuser et al., (1970) which tend to indicate a better performance in subjects with a high adrenaline excretion during understimulation (vigilance task) but worse during overstimulation as compared to the subjects with low adrenaline excretion.

The training period obviously resulted in a significantly different change in the physical performance of the groups (Table II). However, we did not find any significant differences between the groups in the performance during the CRT or in the pattern of the urinary excretion of catecholamines during the relative rest or the CRT.

Acknowledgement

The authors acknowledge the support provided by a grant from The Finnish Research Council for Education and Sports, Ministry of Education, Finland and the technical assistance provided by Veikko Vihko, B.Sc. (chemistry), Mr. Aarno Sorsa (CRT-apparatus), Miss Kirsti Vaarna (assistant), Mrs. Liisa Havola-Pitkänen and Miss Patricia Baker (English revision). We also thank for the support provided by Professor Jeddi Hasan, Director of the Department of Public Health and Professor Esko Karvinen, Director of the Department of Biology of Physical Activity, University of Jyväskylä, Finland.

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TABLE I DESCRIPTIVE DATA OF SUBJECTS

Trained subjects	Age (years)	Height (cm)	Weight (kg)	Control subjects	Age (years)	Height (cm)	Weight (kg)
2	25	166	58.0	1	22	183	72.8
4	23	186	80.1	3	23	174	70.6
6	20	178	72.6	5	24	177	59.8
8	23	172	63.5	7	23	179	67.8
10	21	183	72.5	9	24	183	75.3
12	24	175	63.5	11	25	170	54.9
Mean	22.7	176.7	68.4		23.5	177.7	66.9
S.D.	1.69	6.68	7.39		0.95	4.68	7.24

TABLE II STEADY STATE HEART RATES DURING ERGOMETER WORK BEFORE AND AFTER NINE WEEKS' PERIOD OF ENDURANCE CONDITIONING

Trained subjects no.	During work of 6 minutes 1200 kpm/min[1] Before training	After training	Change during training period	Control subjects no.	During work of 6 minutes 1200 kpm/min[1] Before training	After training	Change during training period
	1	2	3		4	5	6
2	179	153	- 26	1	166	146	- 20
4	138	126	- 12	3	150	134	- 16
6	129	118	- 11	5	172	170	- 2
8	168	147	- 21	7	157	150	- 7
10	131	118	- 13	9	149	145	- 4
12	163	137	- 26	11	173	178	+ 5
Mean	151.3	133.2	18.2		161.2	153.8	7.3
S.D.	19.44	13.60	6.42		9.75	15.23	8.44

Statistical significance between the means of the columns (t - test):

1 - 2 $p < .001$

4 - 5 NS

3 - 6 $p < .002$

(1 According to Åstrand and Ryhming (1954); means of the last two minutes during work

TABLE III URINARY EXCRETION OF CATECHOLAMINES(ng/min) DURING RELATIVE REST AND CHOICE REACTION TEST OF 45 MINUTES BEFORE AND AFTER A NINE-WEEK PERIOD OF ENDURANCE CONDITIONING

Subjects	Before training				After training[2]			
	During rest	During CRT	p[1]	Ratio of CRT/Rest	During rest	During CRT	p[1]	Ratio of CRT/Rest
Trained (6)								
Adrenaline	3.3 ± 1.2	17.4 ± 7.4	< .01	5.3	3.0 ± 1.1	13.5 ± 4.9	< .01	4.5
Noradrenaline	24.0 ± 6.7	35.6 ± 5.7	< .01	1.5	19.1 ± 4.2	31.1 ± 9.3	< .01	1.6
NA/A	8.7 ± 4.7	2.3 ± 0.7	< .05	0.3	8.2 ± 6.4	2.4 ± 0.7	< .05	0.3
Control (6)								
Adrenaline	5.2 ± 3.3	12.5 ± 4.5	< .01	2.4	2.9 ± 1.1	13.0 ± 7.2	< .01	1.5
Noradrenaline	14.8 ± 2.3	23.6 ± 7.3	< .01	1.6	16.2 ± 7.1	25.0 ± 15.0	NS	1.5
NA/A	3.5 ± 1.5	2.3 ± 1.9	NS	0.7	5.9 ± 2.6	2.3 ± 1.5	< .002	0.4
All (12)								
Adrenaline	4.3 ± 2.5	15.0 ± 6.2	< .001	3.5	3.0 ± 1.2	13.2 ± 7.5	< .001	4.4
Noradrenaline	19.4 ± 6.8	29.6 ± 15.7	< .001	1.5	17.7 ± 5.4	28.1 ± 13.5	< .001	1.6
NA/A	6.1 ± 4.3	2.3 ± 1.3	< .05	0.4	7.1 ± 4.8	2.4 ± 1.0	< .01	0.3

(1 t - test for the correlating means between rest and CRT

(2 no significant differences between the groups after training; analysis of covariance with log-transforma ons the pre-training values as covariate and the post-training values as criterion

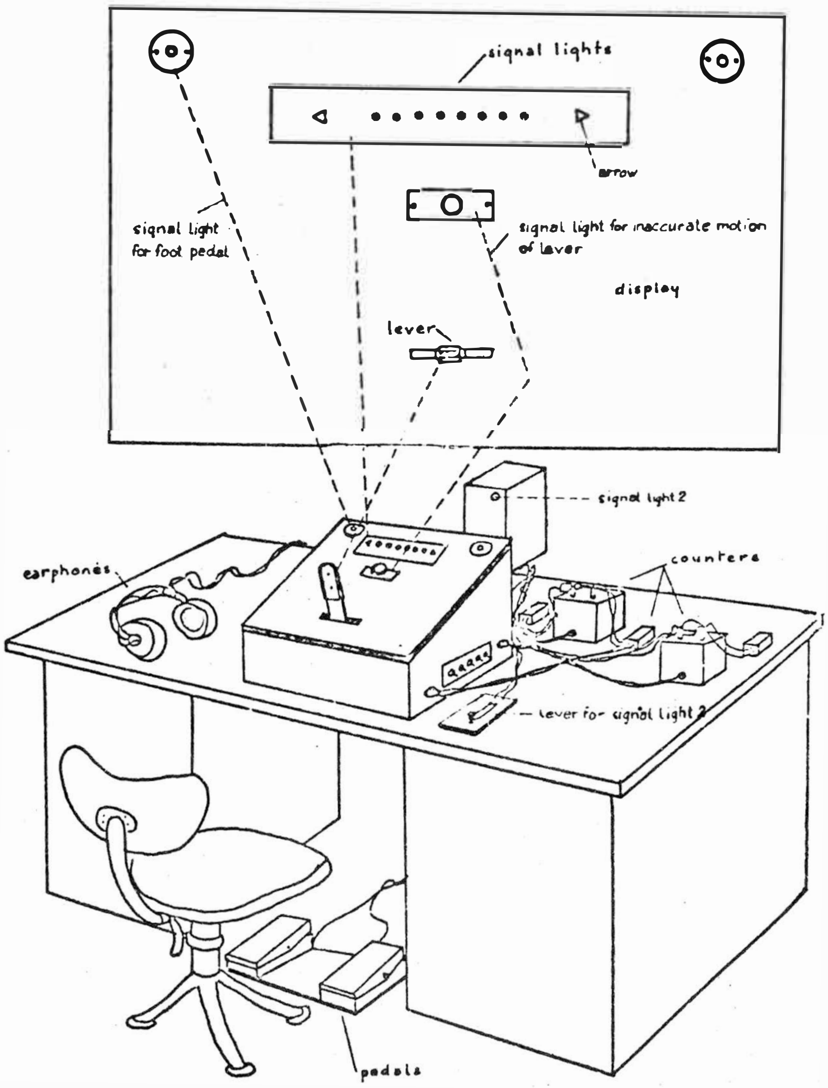

Figure I. Choice reaction test equipment

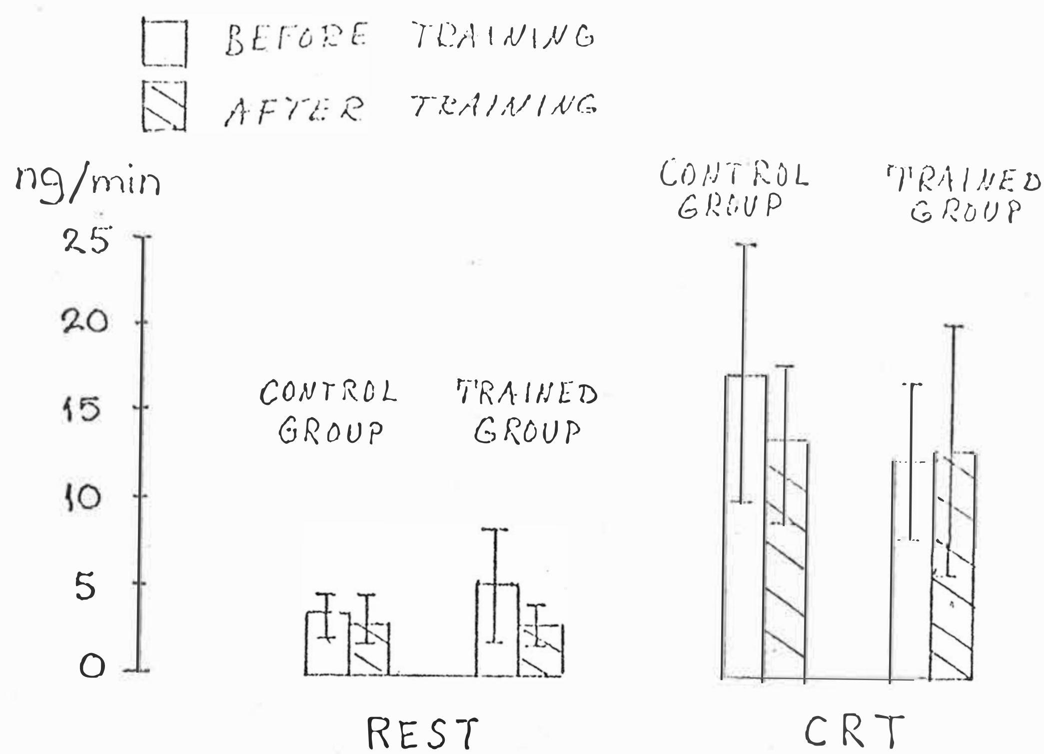

Fig. 2. Urinary excretion of adrenaline during rest and 45 minutes' choice reaction test before and after nine weeks' period of endurance conditioning.

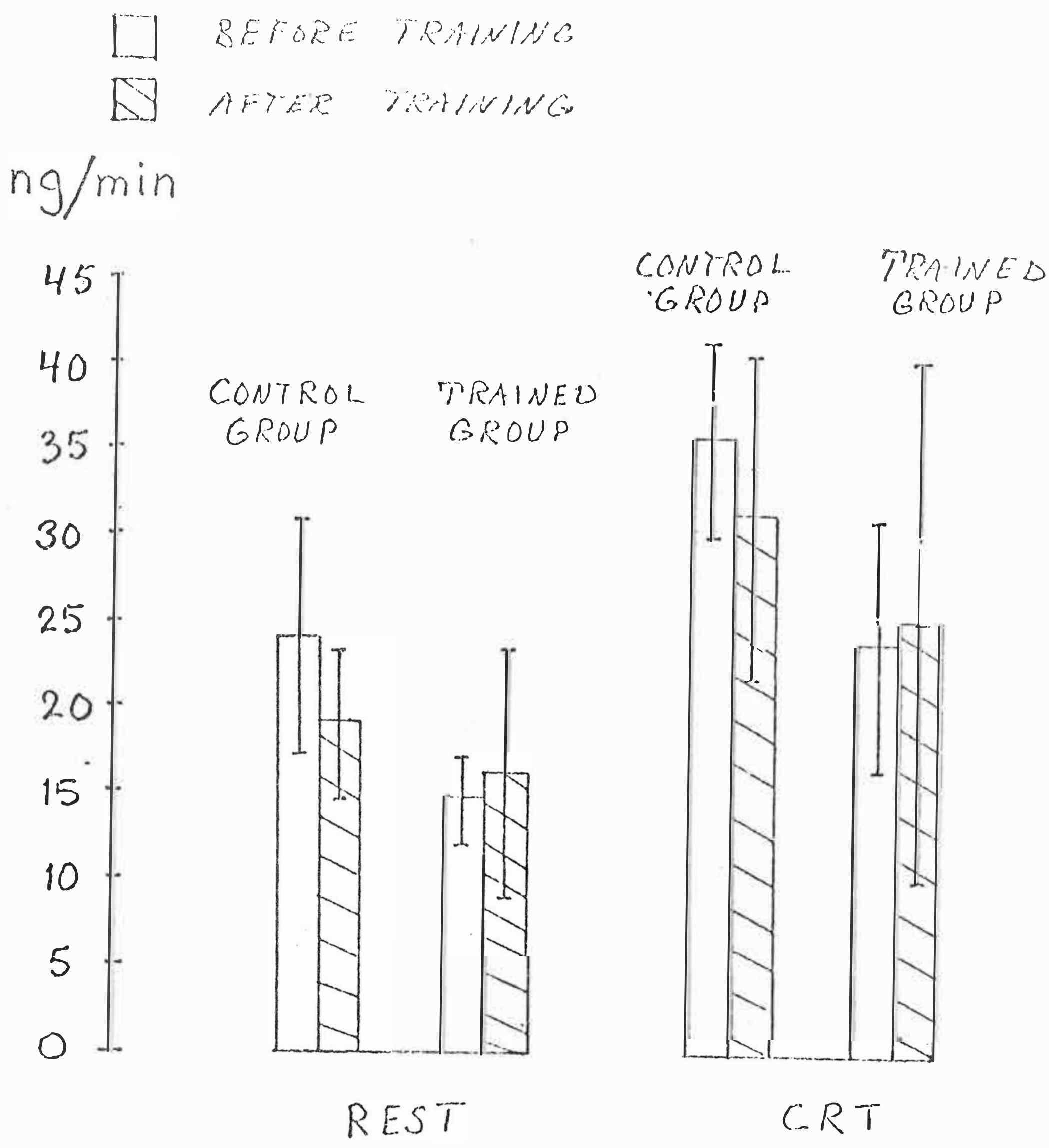

Fig. 3. Urinary excretion of noradrenaline during rest and 45 minutes' choice reaction test before and after nine weeks' period of endurance conditioning

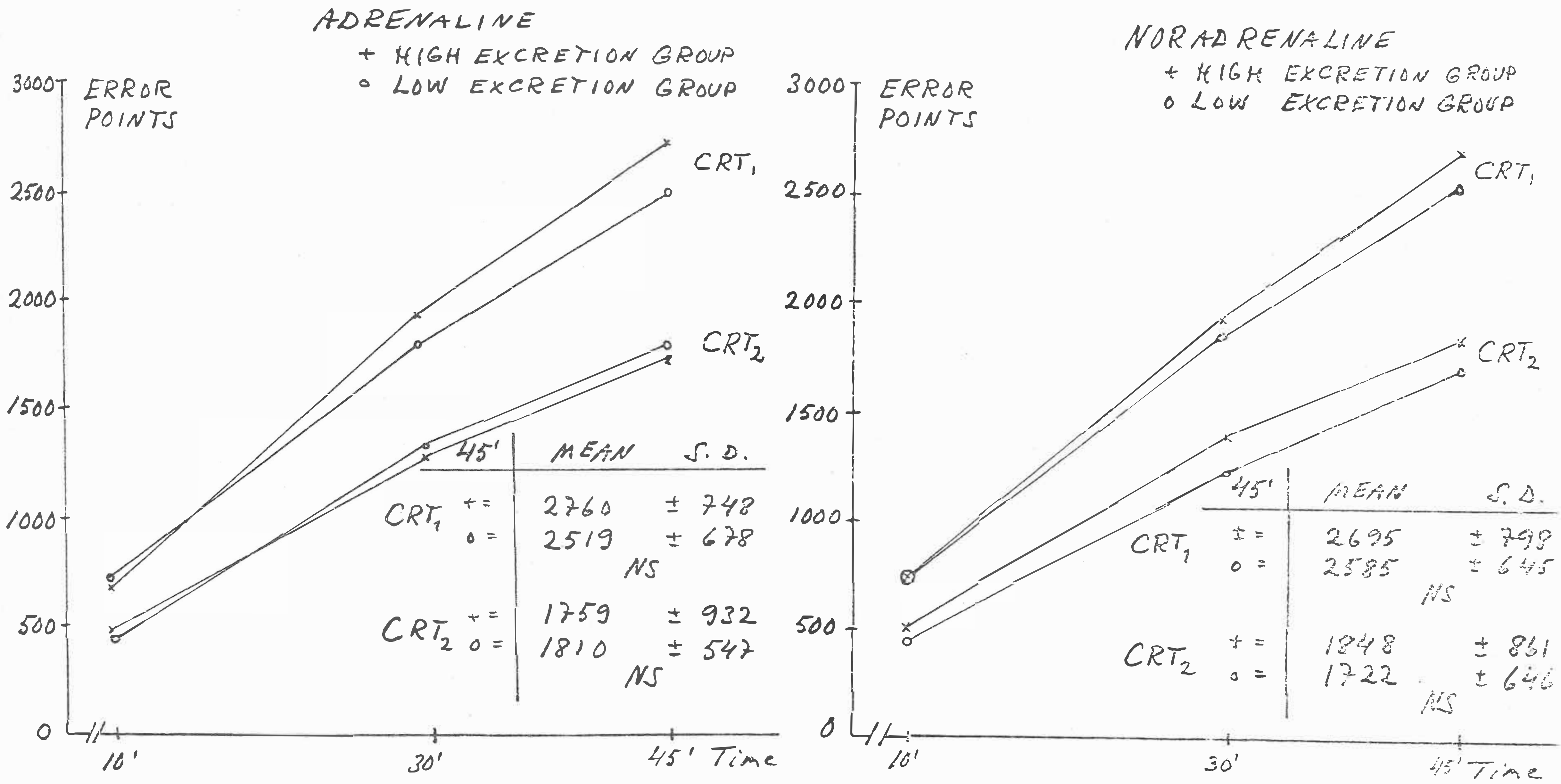

Fig. 4. Total error points 10, 30 and 45 minutes after the outset of a 45 minutes' choice reaction test in group of high and low urinary excretion of noradrenaline and adrenaline

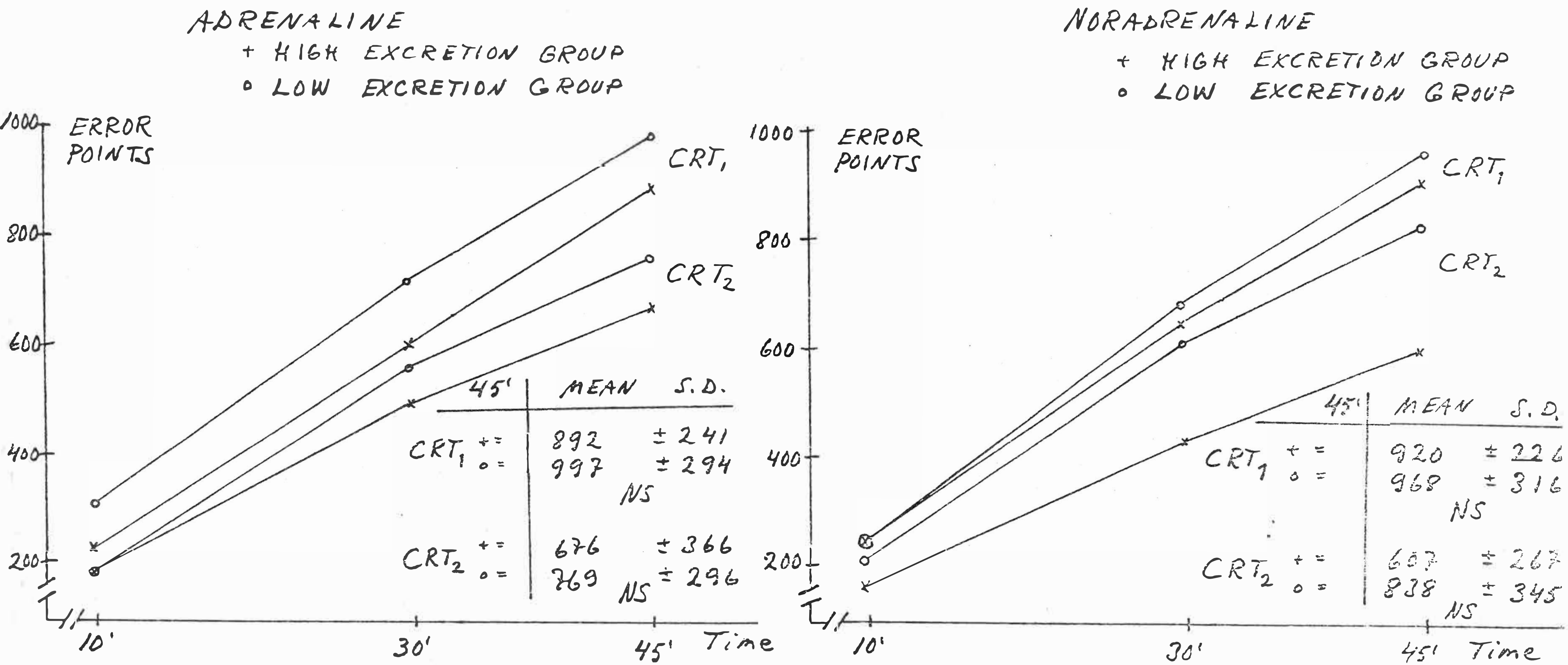

Fig. 5. Total error points in hand movements 10, 30 and 45 minutes after the outset of a 45 minutes' choice reaction test in groups of high and low urinary excretion of noradrenaline and adrenaline

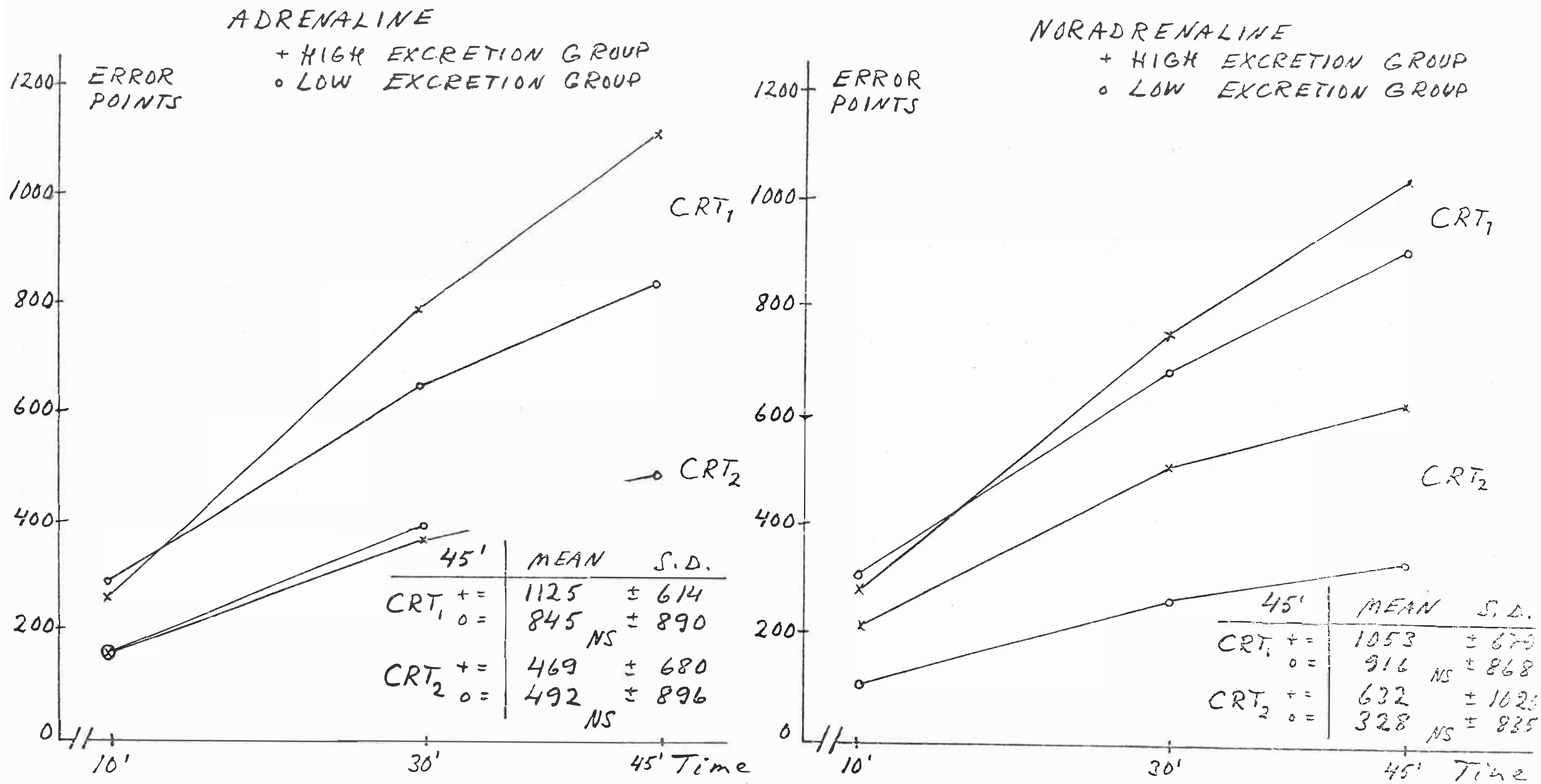

Fig. 6. Total error points in foot movements 10, 30 and 45 minutes after the outset of a 45 minutes' choice reaction test in groups of high and low urinary excretion of noradrenaline and adrenaline

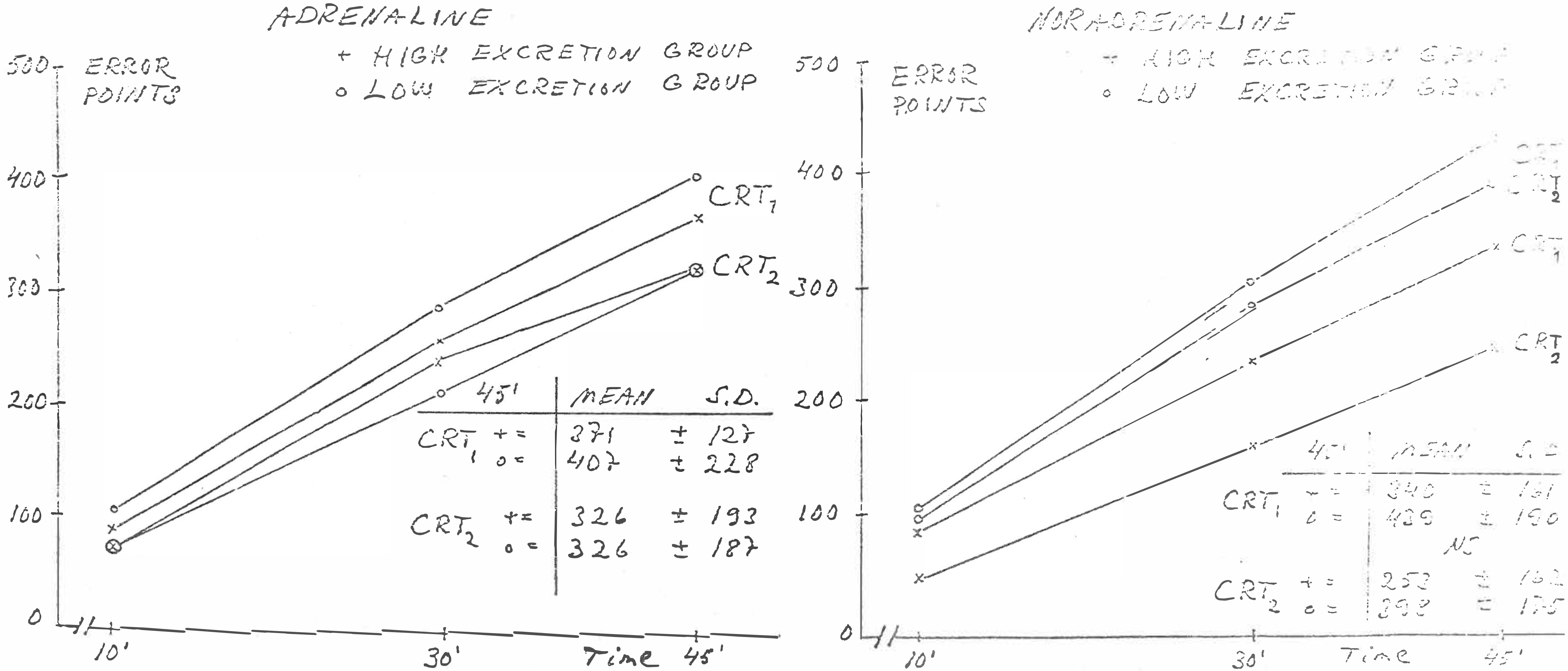

Fig. 7. Non-response rate to light signals 10, 30 and 45 minutes after the outset of a 45 minutes' choice reaction test in groups of high and low urinary excretion of noradrenaline and adrenaline.

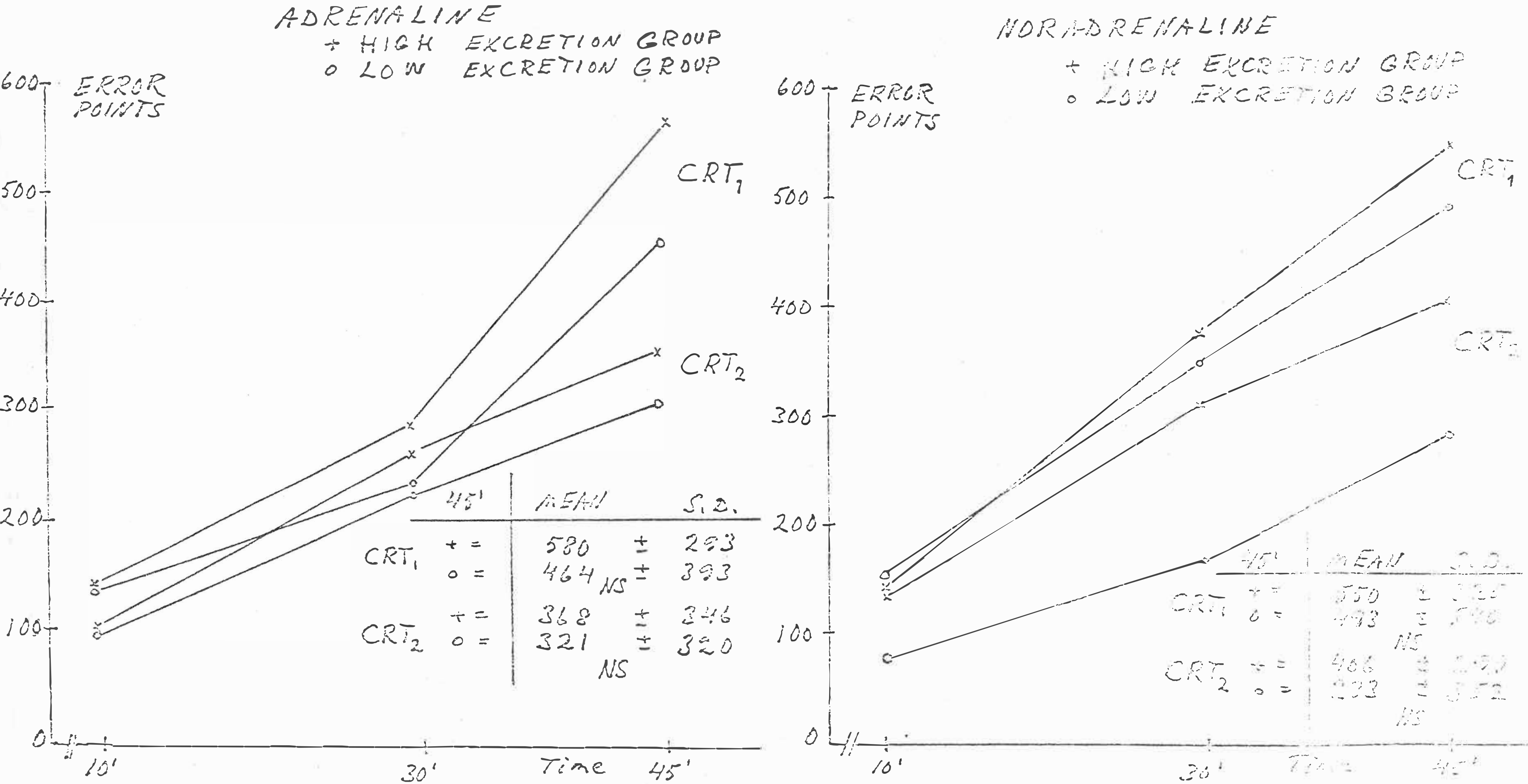

Fig. 8 . Non-response rate to sound signals 10, 30 and 45 minutes after the outset of a [illegible] minutes' choice reaction test in groups of high and low urinary excretion of noradrenaline [illegible] adrenaline.

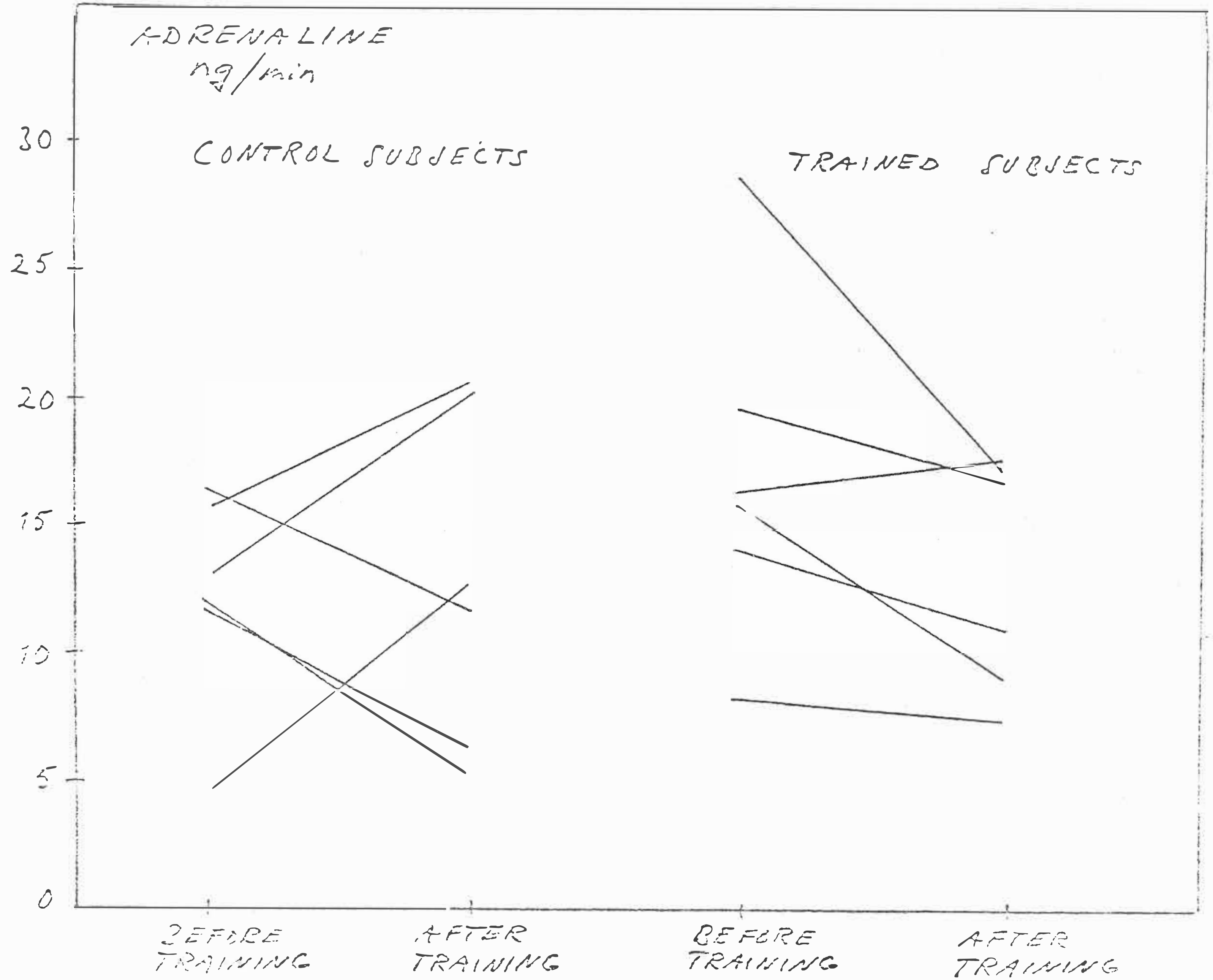

Fig. 9. Urinary excretion of adrenaline during 45 minutes' choice reaction test before and after nine weeks' period of endurance conditioning.

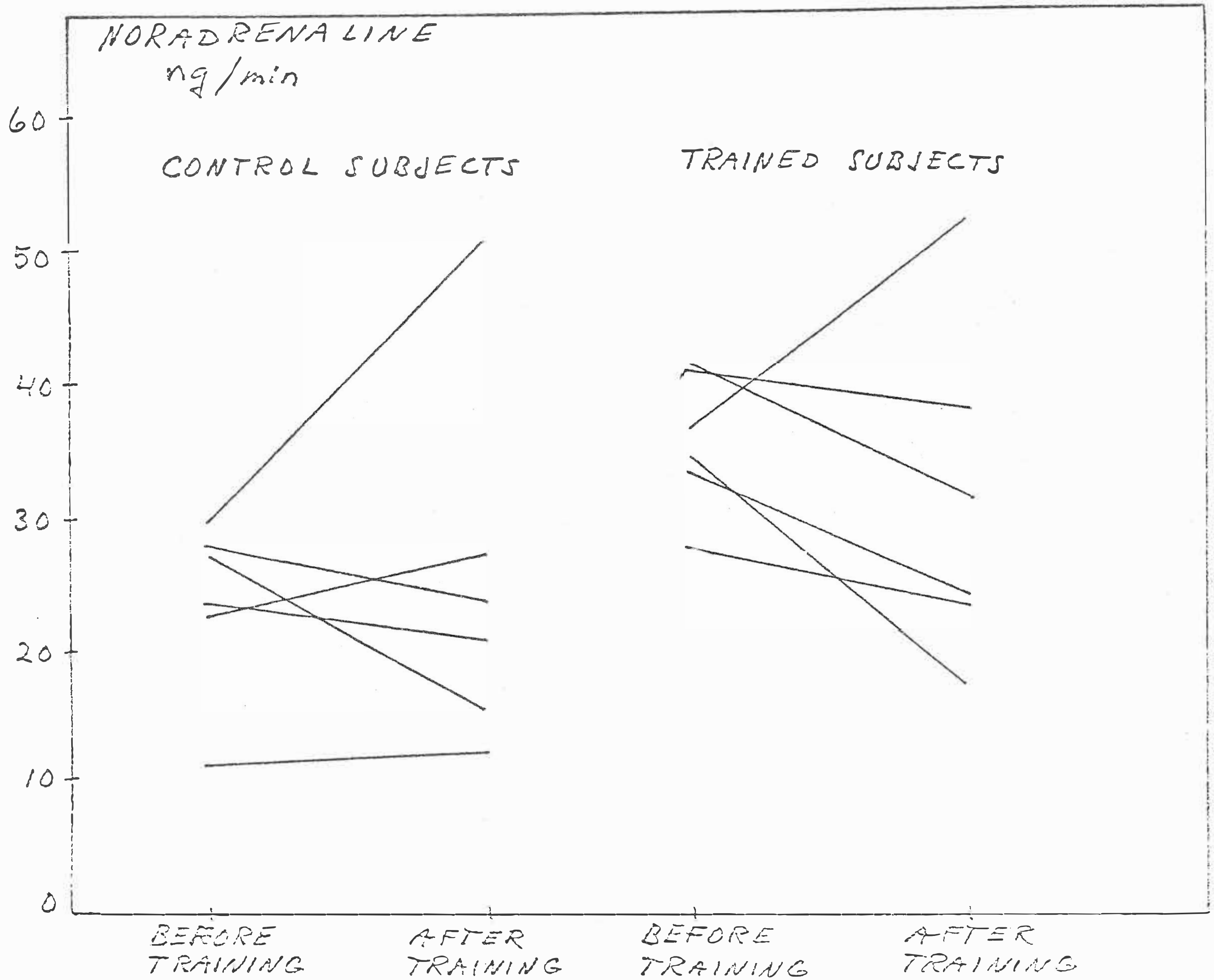

Fig. 10. Urinary excretion of noradrenaline during 45 minutes' choice reaction test before and after nine weeks' period of endurance conditioning.

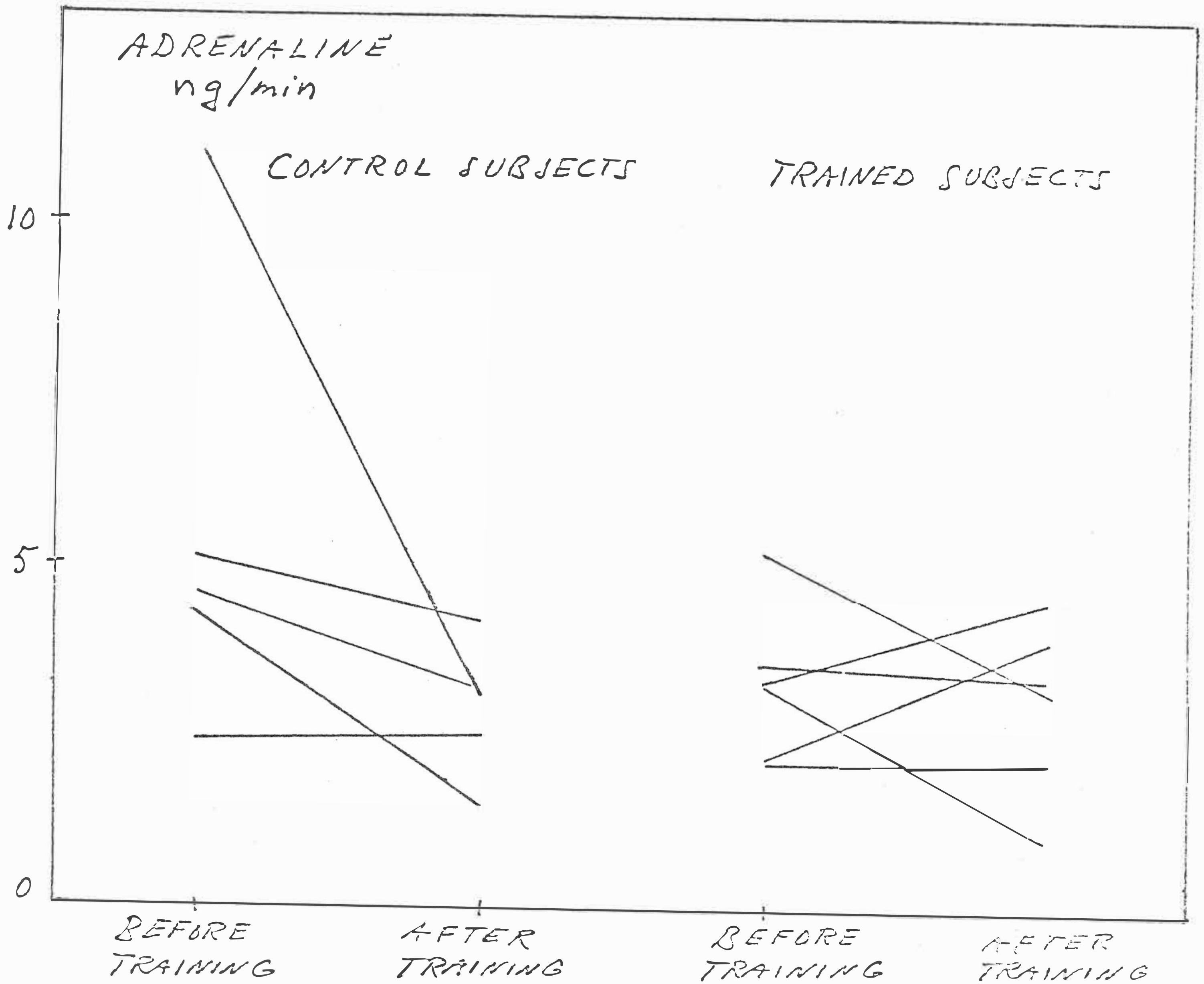

Fig. 11. Urinary excretion of adrenaline during relative rest before and after nine weeks' period of endurance conditioning.

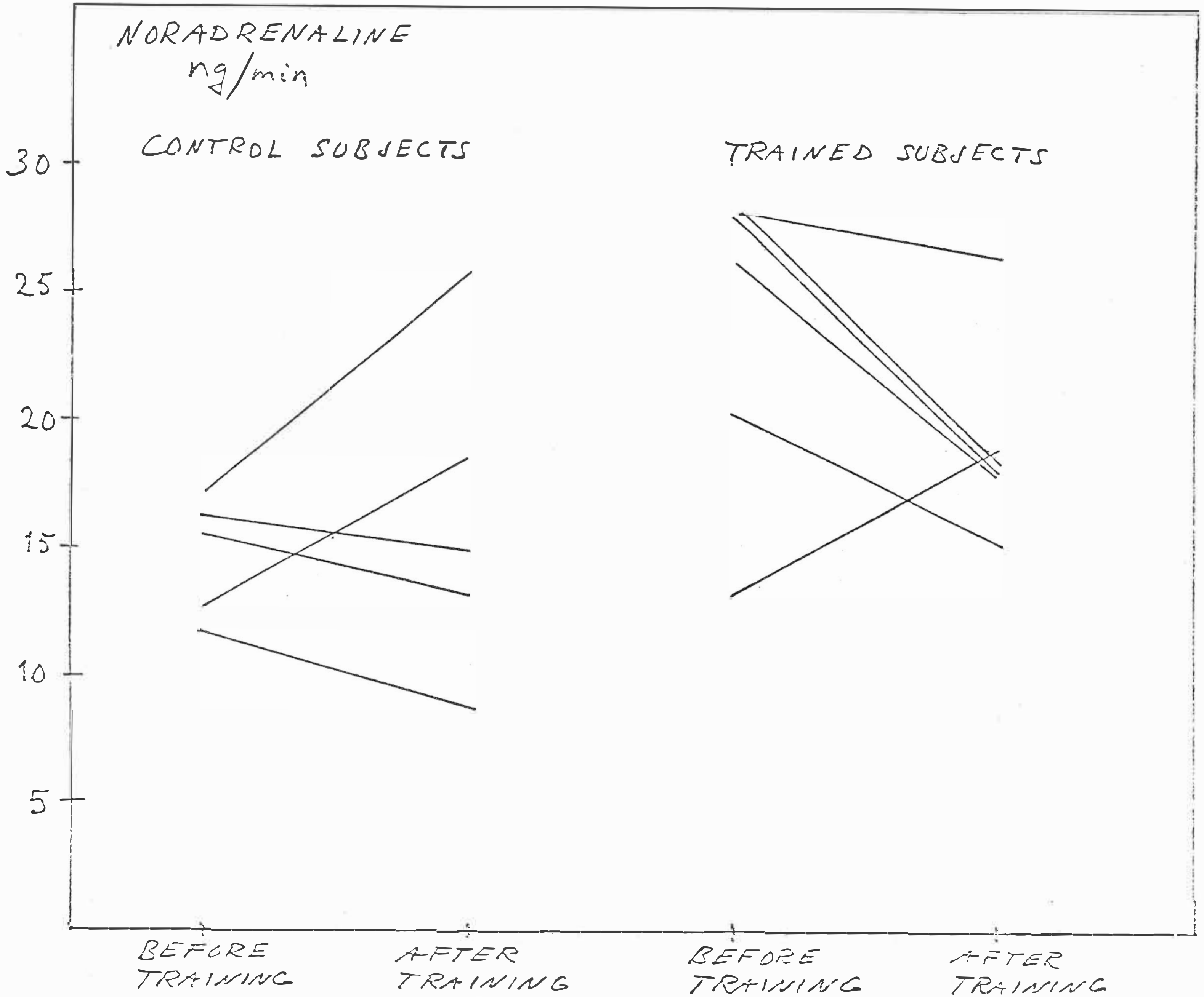

Fig. 12. Urinary excretion of noradrenaline during relative rest before and after nine weeks' period of endurance conditioning.

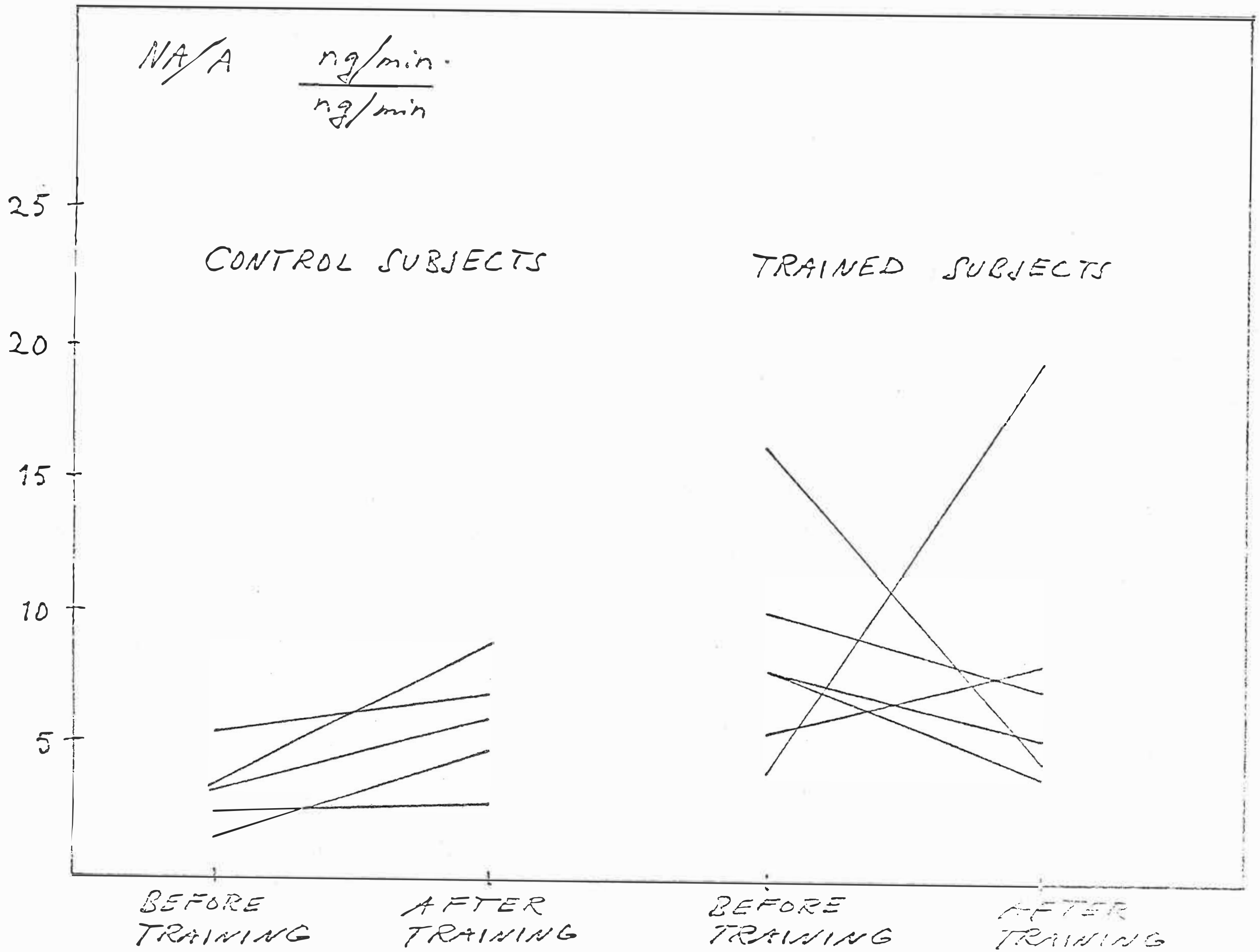

Fig. 13. Ratio of urinary excretion of noradrenaline and adrenaline during relative rest before and after nine weeks' period of endurance conditioning.

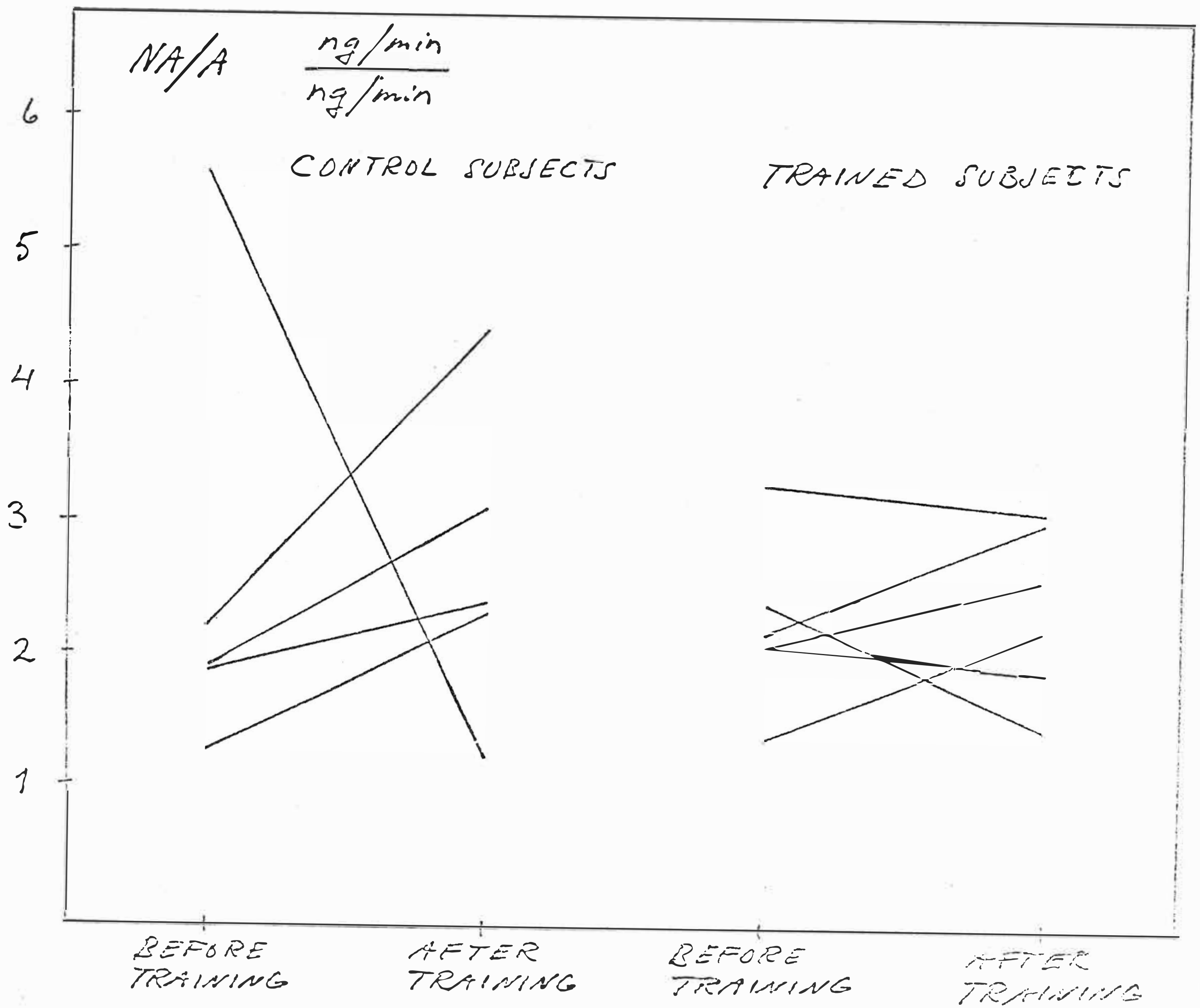

Fig. 14. Ratio of urinary excretion of noradrenaline and adrenaline during 45 minutes' choice reaction test before and after