FOREWORD

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The responsible investigators in this research were Doctors Ben B. Blivaiss and Piero P. Foa of The Chicago Medical School. In this work, they had the active assistance of Ramon Stoner, M.S., Doris Hathy, B.S., Dorothy Billinger, B.S., Inna Priede, B.S., Rita H. Ruthowski, M.S., Lucia Lingis, B.S., and Anita F. Jackson.

The research contained in this report was accomplished between December 1959 and February 1963. Captains Edward B. Magid and Morris J. Mandel, USAF, MC, of the Vibrations and Impact Branch, Biodynamics and Bionics Division, Biophysics Laboratory, 6570th Aerospace Medical Research Laboratories, served as contract monitors. We acknowledge the cooperation of Doctors H. E. von Gierke and R. R. Coermann of the Biodynamics and Bionics Division, 6570th Aerospace Medical Research Laboratories in the planning of these experiments.

Animal experimentation reported herein was performed in accordance with "Principles of Laboratory Animal Care" established by the National Society for Medical Research.

A part of this report has been accepted for publication by the Academic Press in the Proceedings of the International Congress on Hormonal Steroids, Milan, Italy, 1962, entitled as follows:

> Blivaiss, B. B., Litta-Modignani, R., and Priede, Inna: Plasma 17-Hydroxycorticosteroids in Dogs after Whole-Body Vibration.

ABSTRACT

To determine the endocrine and metabolic response of restrained dogs to whole-body vibration, pentobarbital anesthetized and non-anesthetized dogs were vibrated along the z axis while restrained in dorsal recumbency. After vibration of anesthetized dogs at either 4 cps, 0.4 g for 30 minutes or 2 hours, or at 10 cps, 2.3 g for 2 hours, there was an average increase of 4.08 mcg 17 hydroxycorticosteroids (17-OH-CS) per 100 ml plasma and a significant increase in blood epinephrine but not serotonin or norepinephrine. Shaking at 4 cps, 1.7 g for 30 minutes produced less of a change in plasma 17-OH-CS than at 0.4 g. However, shaking at 4 cps for 6 hours led to greater increase in plasma 17-OH-CS at 1.7 g than at 0.4 g. Non-anesthetized dogs shaken at 4 cps for 30 minutes had a greater increase of plasma 17-OH-CS than similarly shaken anesthetized dogs. Possible mechanisms for alterations in endocrine function are discussed.

PUBLICATION REVIEW

This technical documentary report is approved.

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ENDOCRINE AND METABOLIC RESPONSE OF DOGS TO WHOLE-BODY VIBRATION

INTRODUCTION

A variety of studies has been made on aspects of the cardiovascular, respiratory, and functional behavior of animals during whole-body vibration. Our references will be primarily limited to those related to the endocrine and metabolic effects of whole-body vibration. Schaefer et al. (ref. 32) found that castration reliably lengthened survival time in male rats exposed to whole-body vibration. They and others have reported hemorrhage in lungs to be the primary cause of death as a result of vibration. Fowler (ref. 13), using anesthetized, restrained cats produced lethal vibration levels in 2 to 25 minutes at accelerations of 10-15 g at 5-20 cps. The cause of death was considered to be due to the mechanical damage to either heart or lungs. Schaefer et al. (ref. 32) found that the lethality of vibration increased with an increase in frequency and g level (20-40 cps, 5-20 g). Both Roman (ref. 30) and Schaefer et al. (ref. 33) agreed that tissue damage appeared to have been caused by distortions and relative displacement of tissues or organs.

The adrenal gland is believed to be involved in protecting the animal against vibration stress. One would expect to find a decreased eosinophil count, and a decreased sodium output as a corollary of increased adrenal cortex secretion but these measurements have not given consistently conclusive results. Riopelle et al. (ref. 29) vibrated unanesthetized but restrained monkeys for periods up to 8 hours at peak-to-peak amplitudes of 0.25 in. and 0.50 in. inclusive at 10 cps. Three of 5 surviving monkeys showed at least a 50% decrease in eosinophils after 8 hours of vibration, but the eosinophils increased markedly 2 days later. These findings suggested that the reserve of adrenocortical hormones necessary for a percentage decrease of 50% or more in eosinophils was exhausted after 48 hours. In rats vibrated at 60-130 cps, 8-9 g for 12 hours per day, Guillemin and Wechsberg (ref. 15) reported no statistically significant change in the eosinophil count. Following prolonged vibration, Cope and Polis (ref. 7) found no significant changes in eosinophil level but an increased neutrophil count and a lymphopenia which could be indicative of an increased adrenal cortical discharge. Fowler (ref. 13) found an increased serum potassium level but Loeb (ref. 17) reported no change in urine albumin, potassium and sodium concentration.

In view of the increased workload required to maintain posture in the ever-changing environment during vibration, one might expect an increase in metabolic activity of vibrated animals, especially if unrestrained.

Carter et al. (ref. 4) found that the vibration of rats at 3 cps caused a decrease in oxygen consumption but intense vibration at 10 cps or more resulted in its increase. Hoover et al. (ref. 16) found that the vibration of unrestrained rats at 20 cps for one-half hour per day for 7 days resulted in no change in growth rate, food intake, fecal output or body weight. Water intake and urine volume tended to decrease over the test period. Creatine excretion was not altered. In a study of chronic vibration of restrained rats, Schaefer et al. (ref. 32) found a decrease in appetite, weight gain, running and response to food awards.

Body vibration may affect suspended organs (e.g. intestines) differently from relatively fixed organs (e.g. pancreas and adrenals), leading to traction-stimulation of both types of structures. Pancreas, adrenals and intestines are richly endowed with sensory organs and may respond to stimulation by secreting specific hormones, such as serotonin, epinephrine and norepinephrine.

In human subjects (19, 20, 46), vibration caused a combination of precordial pain, dyspnea, interference with respiration and valsalva maneuver, followed after the end of vibration by facial flush, dysphoria, euphoria, fatigue and depression suggesting possible alterations in metabolic and hormonal functions (refs. 19, 46). In view of the stresslike combination of pain, anxiety and cardiovascular changes encountered in humans and the behavioral and physiological changes in animals, we investigated the changes in the blood level of hydrocortisone, catecholamines and certain metabolic constituents in dogs exposed to whole-body vibration especially at 1 to 20 cps.

Little is known about the reaction of the endocrine system to mechanical vibrations at different frequencies, particularly the important range from 1 to 20 cps.

The results outlined below will aim at comparing on a quantitative basis the biochemical differences in the response of anesthetized and non-anesthetized dogs and, also, to evaluate the function of vibratory frequency and amplitude on response to vibration. In view of the known effects of the catecholamines, of serotonin and of the adrenal cortical hormones on psychological alertness, physiological efficiency and physical resistance, it was considered that a study of these parameters may lead to a better understanding of factors determing suitability for space flight and overall performance of human subjects.

EQUIPMENT AND METHODS

Dogs were shaken along the longitudinal axis using a horizontally vibrating test stand which could be adjusted as to frequency and amplitude of sinusoidal movement.

The amplitude was measured by a direct writing stylus. The frequency of movement of the table was determined electronically through a magnetic pickup and recorded on a Sanborn recorder. The vibration table was a Model VU-DM-100 of the L. A. B. Corporation. In order to increase the acceleration obtainable with this machine at low frequencies, a mechanical amplifier was employed which increased the maximum double amplitude of the machine from 12.5 to 54 mm (ref. 25).

Dogs were attached firmly to the test stand by binding them in a canvas jacket in a manner that the ventral surface of the abdomen was free below the level of the ribs. By means of ropes attached to the canvas jacket as well as to the limbs, the dog was firmly secured to the table in a supine position. With this type of attachment, Nickerson et al. (ref. 26) showed that the transmission of force from the vibrating platform to the subject was highly efficient.

During the vibration of animals for periods over 30 minutes, a rise in rectal body temperature was observed. Rectal temperature was taken at 30 to 60-minute intervals by means of a rectal thermometer or an indwelling rectal electronic tele-thermometer (Yellow Springs Instrument Co., Tele-Thermometer Model No. 43TA).

In our early experiments the animals were placed on a coppertube water cooling system to counteract the rise in body temperature. Water flow in the coppertube cooling system was increased or decreased in accordance with changes in the animal's temperature from previbration level. While this method was effective in controlling the dog's temperature, during long-term vibration the copper tubing caused abrasions on the dog's skin. To avoid these abrasions, we now employ a McQuiston Conductive Rubber Water Mattress, which is irrigated with cold tap water, as needed, to maintain a constant body temperature. This device proved to be effective in keeping the dog's temperature constant and is not irritating its skin.

The dogs were anesthetized by intravenous administration of sodium pentobarbital 30 minutes prior to the start of vibration. A heparinized control blood sample was taken immediately before the start of vibration, or 30 minutes after the onset of anesthesia. A second blood sample was taken immediately after the end of vibration in short-term experiments or at intervals during long-term experiments. The dogs were kept under anesthesia during the whole experiment.

When the experiments were to be performed in non-anesthetized dogs, the animals were given an intravenous injection of thiamylal sodium, an ultra short-acting barbiturate at a dose of 10 mg/kgm. This dose kept the dog in an anesthetized state for about 10 to 15 minutes which was adequate for tying the dog to the vibrating test stand without struggling or excitement.

By the time the vibration was started, the dog appeared to have recovered from the anesthesia and was conscious. Blood samples were taken before anesthesia, at intervals during vibration, and at end of shaking period.

Plasma hydrocortisone was measured using the method of Eik-Nes (ref. 10), which utilizes a benzene-water partition and the Porter-Silber (ref. 27) color reaction or by fluorescence in sulfuric acid according to the procedure of Silber et al. (ref. 35). Serotonin was determined by the methods of Udenfriend et al. (ref. 41) and Waalkes (ref. 44). Catecholamines were determined directly in plasma by the method of Cohen and Goldenberg (ref. 6) and Menger et al. (ref. 23), and in urine by the method of De-Schaepdryver (ref. 8) and von Euler and Lishajka (ref. 42) which measures the metabolic end product, 5-hydroxyindoleacetic acid. Blood glucose was determined by using the method of Nelson (ref. 24), lactic acid by method of Barker and Summerson (ref. 1) and phosphate by method of Berenblum and Chain (ref. 3).

Sixteen of the dogs were also exposed to a sham experiment as controls for the effects of anesthesia and handling on blood hydrocortisone levels. All experiments were performed at approximately the same time of the day to avoid the variations known to exist in the diurnal cycles of hormone secretions.

RESULTS

Anesthetized Dogs

Plasma Hydrocortisone: Vibrating the dogs at a frequency of 10 cycles per second with a double amplitude of 12.5 mm, and a gravitational force of 2.3 g for 120 minutes, produced an average increase of 4.08 mcg of 17-OH-CS per 100 ml of plasma (See Table 1).

Since it has been shown by Magid et al. (ref. 19) that in the human the lowest tolerance to whole-body vibration occurred at approximately 4-8 cps, and by Nickerson et al. (ref. 26) that 3-5 cps are the resonant frequencies for most of the abdominal viscera of the dog, another series of dogs was shaken at 4 cps, 12.5 mm, 0.4 g for 120 minutes. The results were similar to those obtained at 10 cps for 120 minutes. When the vibration lasted only 30 minutes, plasma 17-OH-CS levels showed a smaller increase. When the amplitude was increased to 25 mm and 0.8 g, there was a further decrease in response. At an amplitude of 50 mm and 1.7 g, there was no change from the pre-shake level.

To determine the effects of longer periods of vibration, anesthetized dogs were shaken at 4 cps and at amplitudes of 12.5, 25 and 50 mm for 6 hours (See Table 2).

TABLE 1

Plasma 17-OH-CS in Pentobarbital Anesthetized Dogs

Vibration					Plasma 17-OH-CS mcg per 100 ml plasma			
CPS	AMPLITUDE mm	G	TIME-MINUTES	NO.	Pre-Shake Average	After Shake Average	Mean Diff. ± S.E.	P
10	12.5	2.3	120	6	2.22	6.30	4.08±0.76	< 0.01
4	12.5	0.4	120	7	1.78	5.67	4.03±0.41	< 0.001
4	12.5	0.4	30	5	1.46	4.2	2.74±0.93	< 0.05
4	25	0.8	30	4	1.51	2.59	1.10±0.69	
4	50	1.7	30	8	1.51	1.58	0.19±0.14	
SHAM			120	6	1.60	1.72	0.76±0.62	
SHAM			30	5	1.16	1.47	0.3 ±0.19	

TABLE 2

Plasma Hydrocortisone after Whole-Body Vibration of Dogs at 4 CPS

Double Amplitude mm	G	# of Dogs	Plasma Hydrocortisone (mcg/100 ml*)					"p"			
			1 Control	2 3 hrs.	3 △	4 6 hrs.	5 △	M.D. 1 vs 2	M.D. 1 vs 4	P.D. 1 vs 2	P.D. 1 vs 4
12.5	0.4	10	6.90 ±0.74	15.31 ±1.86	8.41	14.10 ±1.35	7.20	< 0.001	< 0.001	< 0.01	< 0.01
25	0.85	8	7.31 ±0.79	16.38 ±1.41	9.06	17.68 ±1.42	10.37	< 0.001	< 0.001	< 0.001	< 0.001
50	1.7	5	6.58 ±0.65	16.8 ±1.3	10.22	20.76 ±2.94	14.18	< 0.001	< 0.01	< 0.01	< 0.02

△ = Mean Difference from Control * = Mean ± S.E.

M.D. = Comparison of Difference of Means of Columns Indicated

P.D. = Comparison of Paired Differences of Columns Indicated

At all amplitudes there were marked and statistically significant increases of plasma 17-OH-CS above the control levels after 3 and 5 hours of vibration. However, there were no statistically significant differences between values at 3 and 6 hours for vibration at the same amplitude. Neither were significant differences found in plasma hydrocortisone levels upon comparison of values after 3 or 6 hours of vibration respectively between the 3 amplitudes (12.5 mm, 25 mm, or 50 mm) utilized.

At 28 cps, using an amplitude of 6 mm, there was only an average increase in hydrocortisone of 1.8 mcg per 100 ml plasma after 3 hours, and of 9.3 mcg per 100 ml after 6 hours. At 16 cps, 12 mm, there was an increase of only 2.4 mcg per 100 ml at 3 hours, but the dogs died after 4 to 5 hours of vibration.

Upon autopsy of the animals, which died during the course of vibration, the most common pathological findings were a passive congestion of the lungs, liver and kidney, adhesion of kidney capsule to its cortex (unrelated to vibration) and petechial hemorrhage of the gastric and duodenal mucosa. Other findings observed in single instances were hemorrhage into the pericardial sac, increased fibrosis of spleen tissue with signs of fresh hemorrhages, congestion of the Circle of Willis, congestion of cerebrum and cerebellum, and tinges of blood in the cerebrospinal fluid. The pathological findings suggest a disturbance in blood flow and a breakdown of capillary or small vessel integrity.

Blood Serotonin, Catecholamines and Other Constituents: Shaking anesthetized dogs at 6 or 10 cps for 2 hours resulted in a statistically significant increase in blood epinephrine ($P \leq 0.01$ and total catecholamines ($P < 0.05$). No significant changes were observed in serotonin and norepinephrine (Table 3).

No clear pattern of change was observed in the urinary excretion of catecholamines (See Table 4). Total catecholamine values varied between 30 and 90 mcg per 24 hours of which 30 to 85 mcg were represented by norepinephrine and only 0 to 5 mcg by epinephrine. Shaking at 6 or 10 cps did not appear to cause any consistent changes in urinary excretion of catecholamines.

To determine the minimal amount of vibration that would produce a significant change in serotonin or catecholamines, a series of experiments were performed with vibration at 4 cps using amplitudes of 12.5, 25 and 50 mm for 30 minutes.

TABLE 3

BLOOD SEROTONIN AND CATECHOLAMINE LEVELS IN DOGS AFTER VIBRATION AT 6 OR 10 CPS FOR TWO HOURS

	Before Shaking	After Shaking
No. of Determinations	16	13
No. of Dogs	12	8
Mean Values (γ/ml) Serotonin	0.14	0.20
No. of Determinations	12	13
No. of Dogs	12	8
Mean Values (γ/ml)		
Epinephrine	0.38	1.33 ($P < 0.01$)
Nor-epinephrine	1.71	2.06
Total Catecholamines	2.09	3.39 ($P < 0.05$)

TABLE 4

URINARY CATECHOLAMINES EXCRETION IN DOGS

	No. of Cases	
	Increased	Unchanged or Lowered
Total Catecholamines	2	9
Epinephrine	9	5
Nor-epinephrine	4	7

As seen from Tables 5 and 6, blood serotonin, catecholamines, glucose, lactic acid and hematocrit remained within the normal range of values and no significant changes occurred after shaking.

Non-anesthetized Dogs

In order to obtain a better comparison between the response of dogs and men to vibration, a series of experiments were undertaken to determine the response to vibration in non-anesthetized dogs.

One sees in Table 7 that in 7 dogs shaken at 4 cps and 1.7 g for 30 minutes, 17-OH-CS increased an average of 9.0 mcg per 100 ml of plasma. In 2 dogs shaken at 16 cps and 15 mm, hydrocortisone increased 8.5 mcg after 3 hours and 11.2 mcg per 100 ml of plasma after 6 hours, respectively.

The non-anesthetized dog is much more sensitive to the sensory stimuli of vibration than the anesthetized one even under conditions which do not appear to cause any measurable changes in the anesthetized dog.

TABLE 5

EFFECT OF WHOLE BODY VIBRATION AT 4 CPS FOR THIRTY MINUTES ON BLOOD AND PLASMA CONSTITUENTS

CONSTITUENTS	12.5 mm		25 mm		50 mm	
	Before	After	Before	After	Before	After
Total Catecholamines (gamma/liter)	2.88	2.97	2.73	2.53	3.70	3.24
Nor-epinephrine (gamma/liter)	2.02	2.12	1.96	1.82	2.88	2.47
Epinephrine (gamma/liter)	.86	.85	.77	.71	.82	.77
Serotonin (gamma/ml)	.31	.27	.29	.34	.247	.26
Blood Sugar (mg%)	75	73	72	76	75	67
Blood Lactic Acid (mg%)	9.4	10.2	8.3	10.8	7.2	8.6
Hematocrit (%)	42	44	41	43	40	42

TABLE 6

URINARY EXCRETION OF CATECHOLAMINES AFTER VIBRATION AT 4 CPS FOR THIRTY MINUTES

CATECHOLAMINES GAMMA/24 HOURS	AMPLITUDE								
	12.5mm			25mm			50mm		
	before	after 24 hours	after 48 hours	before	after 24 hours	after 48 hours	before	after 24 hours	after 48 hours
Total	46.3	39.7	44.3	38.2	42.3	39.8	41.8	40.2	37.9
Epinephrine	2.1	2.6	1.9	1.7	2.3	2.1	1.6	1.8	2.0
Nor-epinephrine	44.2	37.1	42.4	36.5	40.0	37.7	40.2	38.4	35.9

TABLE 7

PLASMA 17-OH-CS IN NON-ANESTHETIZED DOGS

Vibration					Plasma 17-OH-CS μg per 100 ml plasma			
CPS	Amplitude	G	Time - Minutes	No.	Pre-Shake Average	After-Shake Average	Mean Diff. ± S.E.	P
4	50	1.7	30	7	4.2	13.2	9.0±2.27	<0.01
SHAM			30	5	3.6	4.7	1.1±0.69	

DISCUSSION

The increased secretion of adrenal cortical hormones during exposure of animals to stress has been emphasized by many investigators (refs. 14, 18, 31, 34). Exposure of dogs anesthetized with sodium pentobarbital to whole-body vibration appears to be no exception as indicated by the increase in plasma 17-OH-CS after vibration at 4 cps, 0.4 g for 30 minutes or at 10 cps, 2.3 g for 120 minutes. With an increase in g force at 4 cps, this effect decreased. Perhaps the secreted 17-OH-CS are rapidly utilized or vibration at 4 cps with a high G stimulates the neurogenic inhibitory centers for ACTH secretion (refs. 11, 21, 22, 28, 39, 40).

In contrast to the decrease in plasma 17-OH-CS, which occurred after 30 minutes of vibration at 4 cps, 50 mm double amplitude, vibration for longer periods results in an elevation of plasma 17-OH-CS.

Whole-body vibration of non-anesthetized dogs produced an elevation of plasma 17-OH-CS even with a stimulus inadequate to produce significant effects in anesthetized dogs. The massive increase in sensory impulses, as well as psychologic factors, probably play an important role in this response.

It is possible that the vibrations used in our experiments (4 cps, 25 or 50 mm for 30 minutes), stimulated the sensorium in such a manner as to cause: (1) Excitation of the inhibitory centers or (2) Depression of the stimulating centers for ACTH secretion, or (3) Reduction in secretion of the humoral substances, which may stimulate ACTH secretion. A reduction in ACTH secretion would, in turn, lead to reduced secretion of adrenal cortex hormone. This reaction to vibration stimuli needs to be investigated in other animal species and at a variety of vibratory frequencies and amplitudes.

Only when dogs were shaken at 6 or 10 cps for 2 hours was there any significant change in blood epinephrine but not in nonepinephrine or serotonin. The lack of any significant change in catecholamines, serotonin, glucose and lactate and pyruvate when dogs were shaken at 4 cps, 12.5-50 mm double amplitude for 30 minutes, suggests that this type of vibration was not a stress to the animal. However, this is not supported by the change in plasma 17-OH-CS. The absence of any change in plasma lactate, pyruvate or glucose suggests that there were no significant alterations in muscle activity or carbohydrate metabolism during the vibration.

SUMMARY AND CONCLUSION

Whole-body vibration of dogs causes a series of alterations in various physiological parameters which leads to a stresslike response as measured by an increase in plasma 17-OH-CS. Plasma 17-OH-CS level provides a means for measuring the effect of vibratory frequency and amplitude on stimulating the sensorium and causing physilogical responses.

Anesthesia appears to decrease the response to vibration but more information is needed on its mechanisms of action. Information is also needed regarding the role of the central nervous system and of other endocrine glands in modifying the response of the adrenals to vibration stress.

The resistance of serotonin and catecholamines to change is an encouraging result and suggests that anesthetized dogs can tolerate a relatively strong exposure to whole-body vibration. Further experiments using greater amplitude of vibration and non-anesthetized animals are necessary to determine the threshold of effective stimulation.

REFERENCES

1. Barker, S. B. and E. H. Summerson, "The Colorimetric Determination of Lactic Acid in Biological Material," Journal of Biological Chemistry, Vol 153, pp 535-554, 1941.

2. Bencosme, S. A., "Studies on the Terminal Autonomic Nervous System with Special Reference to the Pancreatic Islets," Laboratory Investigation, Vol 8, pp 629-636, 1951.

3. Berenblum, I. and E. Chain, "Studies on the Colorimetric Determination of Phosphate," Journal of Biological Chemistry, Vol 32, pp 286-294, 1938.

4. Carter, E. T., E. J. Largent and W. F. Ashe, "Some Responses of Rats to Whole-Body Mechanical Vibration, II. Metabolic Gas Exchange," Arch. Environmental Health, Vol 2, pp 378-382, 1961.

5. Cohen, G. and M. Goldenberg, "The Simultaneous Fluorometric Determination of Adrenaline and Noradrenaline in Plasma," Journal of Neurochemistry, Vol 2, pp 58-70 and 71-80, 1957.

6. Cope, F. E. and D. B. Polis, Some Effects of Prolonged Low Frequency Vibration on the Molecular and Cellular Composition of Blood, Naval Aviation Medical Acceleration Laboratory, Project NM 11-01-12.12, Report 1, Johnsville, Pennsylvania, November 1957.

7. DeSchaepdryver, A. F., "Differential Fluorometric Estimation of Adrenaline and Noradrenaline in Urine," Arch. Int. Pharmacology, Vol 115, pp 233-245, 1958.

8. Eik-Nes, K., "Determination of 17, 21-Dihydroxy-20-Ketosteroid in Blood Plasma," Journal of Clinical Endocrinology and Metabolism, Vol 17, pp 502-511, 1957.

9. Endroczi, E., K. Lissak, E. Bohus and S. Kavacs, "Inhibitory Influence of Archicortical Structures on Pituitary-Adrenal Function," Acta Physiologica, Academy of Science, Hungary, Vol 16, pp 17-22, 1959.

10. Fowler, R. C., "Damage to Animals Due to Vibration," Supplement to 22nd Shock and Vibration Bulletin, Office of Secretary of Defense, Washington, D. C., pp 16-19, 1955.

11. French, A. B., C. J. Migeon, L. T. Samuels and J. Z. Bowers, "Plasma 17-Hydroxycorticosteroid and Blood Cell Changes in the Rhesus Monkey After Whole-Body X-irradiation," Journal of Clinical Endocrinology, Vol 14, p 816 (abstract), 1954.

12. Guillemin, Jr., V. and P. Wechsberg, "Physiological Effects of Long-Term Repetitive Exposure to Mechanical Vibration," Journal of Aviation Medicine, Vol 23, pp 208-221, 1953.

13. Hoover, G. N., W. F. Ashe and L. B. Roberts, "Growth and Metabolic Responses of Rats Exposed to Whole-Body Vibration," American Phsyiological Society, Fall Meeting, Stanford, California, August 1960.

14. Loeb, M., Further Investigation of the Effect of Whole-Body Vibration and Noise on Tremor and Visual Acuity, U. S. Army Report No. 145, April 1954.

15. Long, C. N. H., "The Relation of Cholesterol and Ascorbic Acid to the Secretions of the Adrenal Gland," Recent Progress in Hormone Research, G. Pincus, Editor, Academic Press, New York, Publishers, Vol 1, pp 99-122, 1947.

16. Magid, E. B., R. R. Coermann, G. H. Ziegenruecker, "Human Tolerance to Whole-Body Sinusoidal Vibration, Short-Time, One-Minute and Three-Minute Studies," Aerospace Medicine, Vol 31, pp 915-924, 1960.

17. Mandel, M. J. and R. D. Lowry, One-Minute Tolerance in Man to Vertical Sinusoidal Vibration in the Sitting Position, Technical Documentary Report No. AMRL-TDR-62-121, Wright-Patterson Air Force Base, Ohio, October 1962.

18. Mason, J. W., "Plasma 17-Hydroxycorticosteroid Response to Hypothalamic Stimulation in the Conscious Rhesus Monkey," Endocrinology, Vol 63, pp 403-411, 1958.

19. Mason, J. W., "Plasma 17-Hydroxycorticosteroid Levels During Electrical Stimulation of the Amygdaloid Complex in Conscious Monkeys," American Journal of Physiology, Vol 196, pp 44-48, 1959.

20. Menger, W. K., K. G. Wakins, and J. L. Bollman, Chemical Quantitation of Epinephrine and Norepinephrine in Plasma, Charles C. Thomas, Springfield, Illinois, 1959.

21. Nelson, N., "A Photometric Adaptation of the Somogyi Method for the Determination of Glucose," Journal of Biological Chemistry, Vol 153, pp 375-380, 1944.

22. Nickerson, J.L. and R.R. Coermann, Internal Body Movements Resulting from Externally Applied Sinusoidal Force, AMRL-TDR-62-81, Wright-Patterson Air Force Base, Ohio, 1962.

23. Nickerson, J.L., G. Nemhauser, C. Gannon, J. Greenman and R. Satzman, "Resonant Frequencies of Internal Body Structure," Federation Proceedings, Vol 20, p 215, 1961.

24. Porter, C.C. and R.H. Silber, "A Quantitative Color Reaction for Cortisone and Related 17, 21-Dihydroxy-20-Ketosteroid," Journal of Biological Chemistry, Vol 185, pp 201-207, 1950.

25. Porter, R.W., "The Central Nervous System and Stress-Induced Eosinopenia," Recent Progress in Hormone Research, G. Pincus, Editor, Academic Press, New York, Publishers, Vol 10, pp 1-27, 1954.

26. Riopelle, A.J., M. Hines and M. Lawrence, The Effects of Intense Vibration, U. S. Army Medical Research Laboratories, Report No. 358, Fort Knox, Kentucky, 1958.

27. Roman, J., Effects of Severe Whole-Body Vibration on Mice and Methods of Protection from Vibration and Injury, WADC Tech. Report No. 58-107, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1958.

28. Sayers, G. and M.A. Sayers, "The Pituitary-Adrenal System," Recent Progress in Hormone Research, G. Pincus, Editor, Academic Press, New York, Publishers, Vol 2, pp 81-115, 1948.

29. Schaefer, V.H., A.J. Link, J.V. Farrar and D. Wrens, Lethality in Rats as a Function of Frequency in Constant Displacement Vibration, AMRL Report No. 390, Fort Knox, Kentucky.

30. Schaefer, V.H. and R.G. Ulmer, Some Behavioral and Physiological Studies in Vibration, USAMRL Report No. 389, Fort Knox, Kentucky, June 12, 1959.

31. Selye, H., "A General Adaptation Syndrome and the Diseases of Adaptation," Journal of Clinical Endocrinology, Vol 6, pp 117-230, 1946.

32. Silber, R.H., R.S. Busch and R. Oslopas, "Practical Procedure for Estimation of Cortisone or Hydrocortisone," Clinical Chemistry, Vol 4, pp 278-285, 1958.

33. Slusher, M.A., "Effect of Brain Stem Lesions on Stress-Induced Corticosteroid Release in Female Rats," Endocrinology, Vol 67, pp 347-352, 1960.

34. Slusher, M.A. and V. Critchlow, "Effect of Midbrain Lesions on Ovulation and Adrenal Responses to Stress in Female Rats," Proceedings of the Society for Experimental Biology and Medicine, Vol 101, pp 497-499, 1959.

35. Slusher, M.A. and J.E. Hyde, "Inhibition of Adrenal Corticosteroid Release by Brain Stem Stimulation in Cats," Endocrinology, Vol 68, pp 773-782, 1961.

36. Udenfriend, S., H. Weissbach and B.B. Brone, "Assay of Serotonin and Related Metabolites, Enzymes and Drugs," Methods of Biochemical Analysis, Vol 6, pp 95-130, 1958.

37. von Euler, C.S. and F. Lishajko, "The Estimation of Catechol Amines in Urine, "Acta Physiologica, Scand., Vol 45, pp 122-132, 1951.

38. Waalkes, T.P., "The Determination of Serotonin (5-HT) in Human Blood," Journal of Laboratory and Clinical Medicine, Vol 53, pp 824-829, 1959.

39. Ziegenruecker, G.H. and E.B. Magid, Short-Time Tolerance to Sinusoidal Vibration, Technical Report 59-391, Wright Air Development Division, Wright-Patterson Air Force Base, Ohio, July 1959.