

The Effects of Coriolis Acceleration During Zero-Gravity Parabolic Flight

JAMES K. COLEHOUR, M.S.

ABSTRACT

Twenty-one normal and four labyrinthine defective (L-D) subjects were exposed to repetitive, twenty-second intervals of (1) zero gravity or (2) zero gravity plus Coriolis acceleration in parabolic flight. The normal subjects showed significant hematological and biochemical evidence of stress in the form of leukocytic changes and alteration in excretion rates of corticosteroids, while the L-D group were virtually free of such changes. Catecholamine excretions were not significantly altered in either group under each of the test conditions.

The zero gravity flight of this experiment did not produce significant change in the muscle metabolism parameters lactic and pyruvic acids and lactic dehydrogenase.

ALTHOUGH BIOCHEMICAL and hematological changes during sustained zero gravity ballistic

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flight have been well documented,^{17, 18} little information is available on the response of labyrinthine-defective (L-D) subjects compared to normals when subjected to repeated, short-cycle, zero-G parabolic flight with and without the added stimulation of Coriolis acceleration. While the latter is not easily tolerated by normal individuals⁸ and may be an incidental problem for the occupants of the space platform,⁸ animals with bilateral labyrinthectomy have been asymptomatic under such bizarre accelerative conditions.¹³ Normal and L-D subjects have been shown to have different excretory patterns for epinephrine, norepinephrine, and 17-hydroxycorticosteroids when subjected to the unusual G forces of acrobatic flight,³ presumably from the stimulation of the hypothalamic-pituitary-adrenal axis. Furthermore, it has not been determined whether a series of parabolic flight maneuvers, with the accompanying load changes imposed on the supportive and functional muscle tissue of the body, would have measurable effects on the glycolytic mechanism parameters such as lactic and pyruvic acids and lactic dehydrogenase. It was the purpose of this experiment to measure the above values in addition to the leukocytic formed elements of the blood in the described zero-G state with and without the added stress of Coriolis acceleration.

METHODS

The zero gravity condition of this experiment was produced in a series of flight parabolas in the KC-135 aircraft expertly carried out by the flight group at Wright-Patterson Air Force Base, Ohio. One mission was flown on each of twelve days, and each mission consisted of an average of twenty-four parabolas with subjects in a zero gravity state twenty seconds during each parabola. The mean time spent at zero-G on each mission was 7.0 minutes. The test conditions were 1) zero gravity as described above and 2) zero gravity during which the added stress of Coriolis acceleration was superimposed by means of the Bárány chair. Each group tested was exposed to only one experimental condition per day. The detailed description of the complete zero-G experiment, of which this is only a part, is given elsewhere.⁹

Twenty-one normal and four deaf subjects, the latter with meningitis-derived bilateral labyrinthine defects, were tested. None were habituated to zero gravity but some had extensive flight time as pilots. The normals were either members of the Armed Forces or civilian employees working in various capacities on the project. The L-D personnel were from Gallaudet College and had previously acted as subjects on the various disorientation devices at the Naval School of Aviation Medicine at Pensacola. With the exception of loss of otolith and semicircular canal function in the L-D subjects, both groups were healthy by the usual standards.

Blood samples were collected before takeoff and at the end of each mission four hours later. Leukocyte, lymphocyte, eosinophil, and differential counts were made by conventional methods. Lactic and pyruvic acids were assayed from immediately prepared perchloric acid filtrates using Calbiochem kits No. 8851 and No. 8852, respectively. Lactic dehydrogenase determinations were done on promptly separated serum by the method of Wroblewski and LaDue.²² Blood values determined immediately postflight were compared to the preflight values with each individual serving as his own control.

Urinary values were determined on samples collected for six hours postflight and compared to similar collections on a day during which only normal ambulatory activity was permitted. Previous experience had indicated³ that this type of reference point is more consistent than a sample collected earlier in the same day because of the considerable change due to diurnal variation. The following urinary parameters were determined: epinephrine and norepinephrine by the method of Crout⁴ and total 17-hydroxycorticosteroids by the method of Kornel.¹⁵ The excretion rates of these hormones were expressed as mean micrograms per hour over a six-hour period.

RESULTS AND DISCUSSION

In the interpretation of the results of an experiment such as this it is necessary to keep in mind the fact that the measured values not only have a diurnal pat-

tern of variation but also that adrenal cortical secretion has a definite, homeostatic, regulatory function. Thus, it is well recognized that, under normal conditions in healthy individuals, the serum corticosteroid levels start to increase upon arising in the morning and are followed after a four or five hour period by slight neutrophilia and definite eosinopenia.^{10, 19, 21} Urinary 17-hydroxycorticosteroid concentration maxima occur at this time also, and the interrelated, periodic nature of these changes has led Bartter *et al.*¹ to designate them as a circadian "map" as shown in Figure 1. Fur-

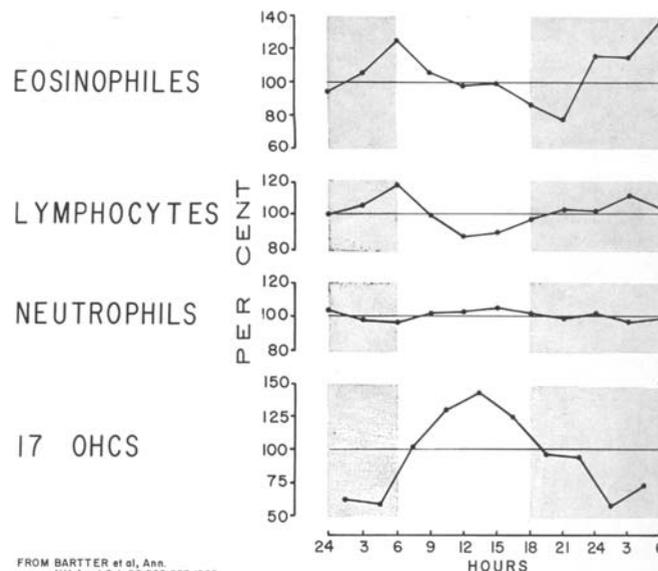


Fig. 1. Related diurnal blood and urinary changes.

thermore, it should be recalled that leukocytic and corticosteroid changes can be produced by exogenous ACTH,^{12, 20} and this in turn has been interpreted as the mechanism of reaction to stressful situations transmitted through the hypothalamic-pituitary-adrenal axis.^{2, 14}

Figure 2 shows the changes in leukocytic formed elements in the blood that occurred during the flights. Under the influence of zero gravity alone, both normal and L-D subjects had increases in total leukocyte and segmented neutrophil counts while lymphopenia and eosinopenia occurred at the same time. Although the changes in the mean values indicated on the bar graphs show the circadian trends that normally occur during the period from 8:00 a.m. to 12 noon, statistical analysis showed that only the normals had significant changes. If we may accept the latter as an indicator of stress, it would be of a low order.

When Coriolis acceleration was applied under zero gravity condition, the changes in the formed elements were also not significant for the L-D's but were highly significant in the normals, except for the lymphocytes. In this case the inference would be that Coriolis acceleration is a highly stressful situation for those with normal canal function in the environment of zero gravity.

Figure 3 shows the unusual secretion pattern of corticoids from both subject groups under both types of stresses. Zero-G alone produced a lower, post-meri-

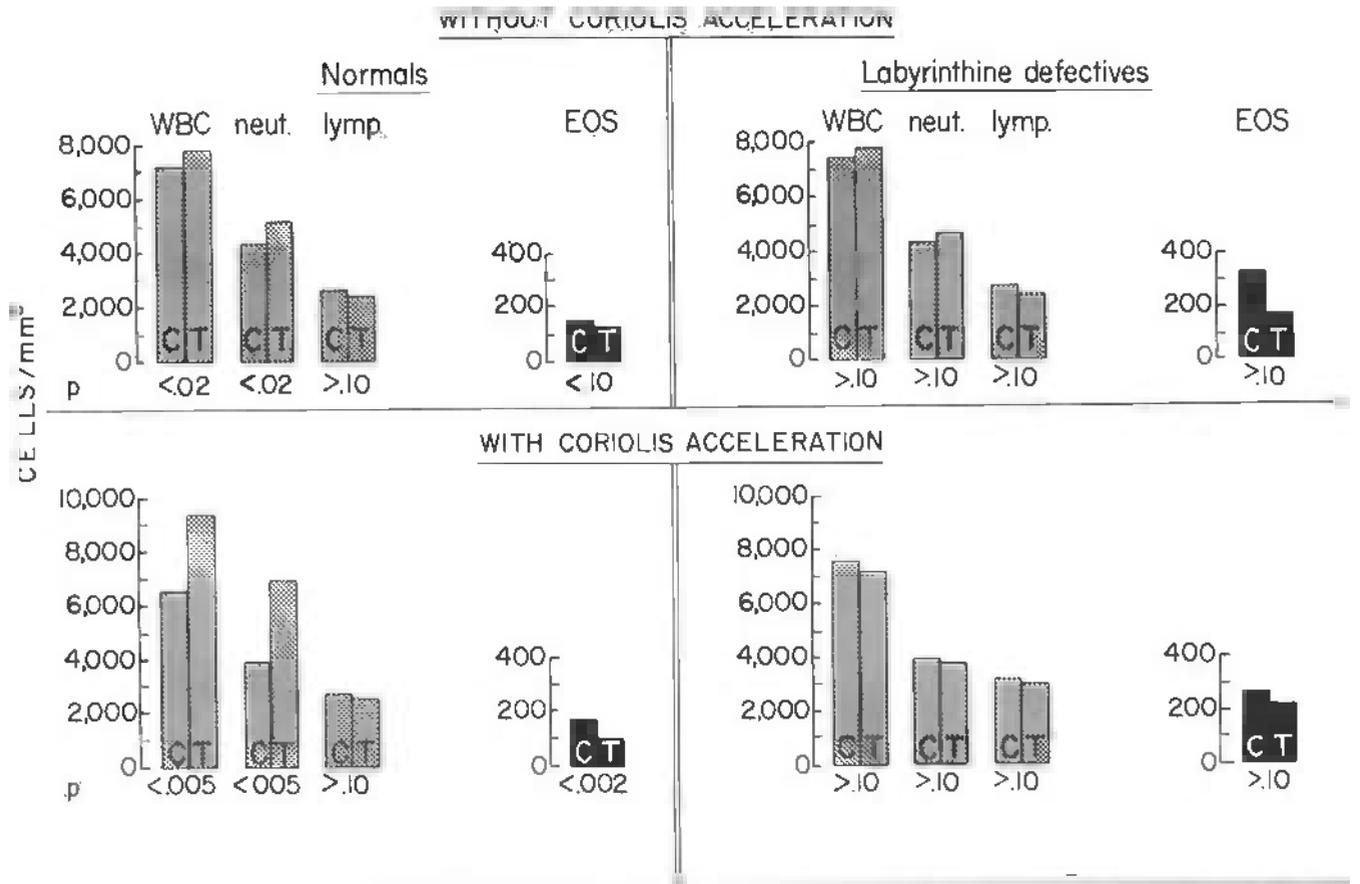


Fig. 2. Variations in leukocytic elements in the blood after zero-G, parabolic flight.

C = Control T = Test

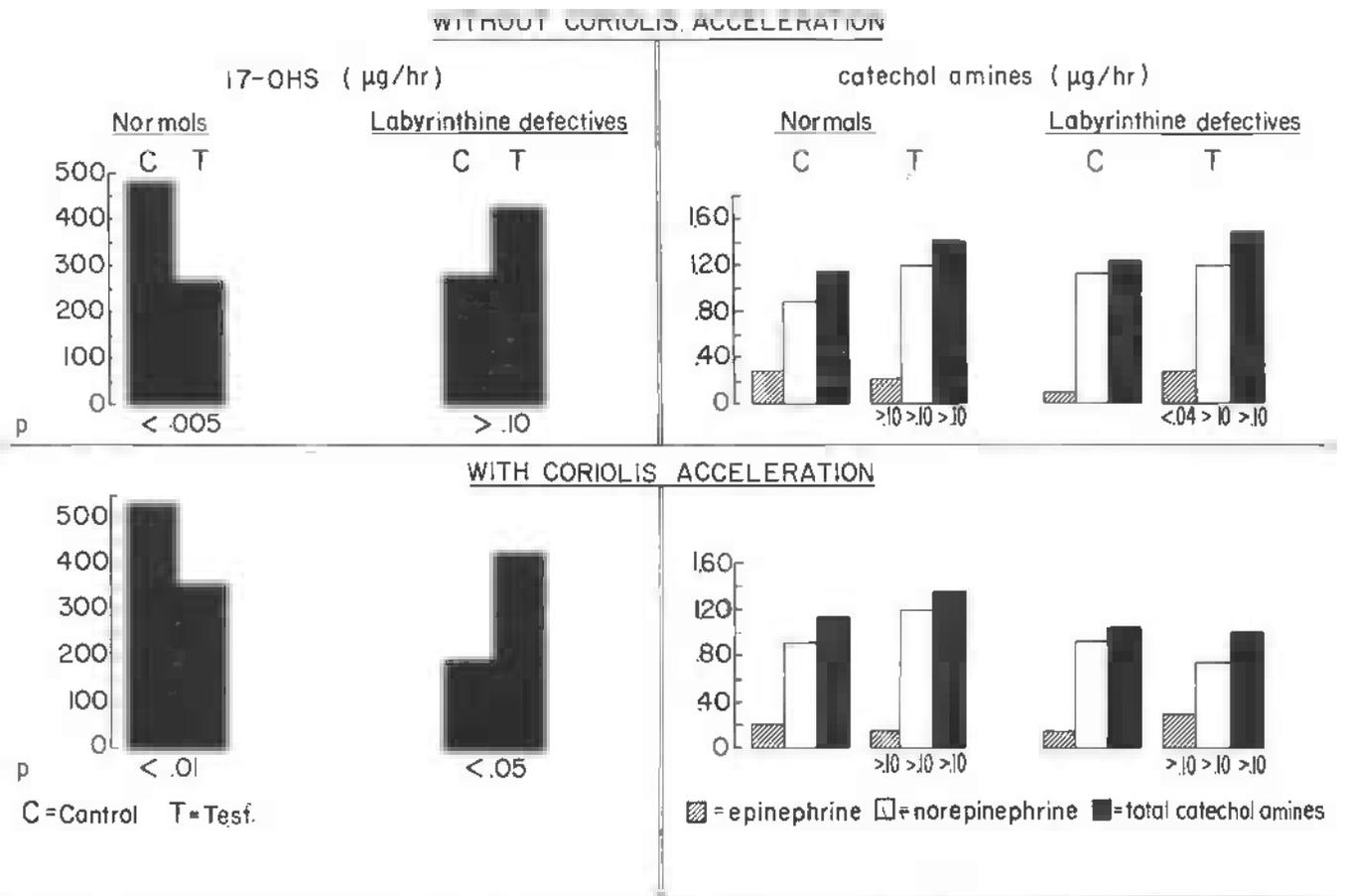


Fig. 3. Stress hormone excretion rates after zero-G parabolic flight.

dional excretion of adrenal cortical hormones in normal individuals after the flight than occurred at a similar time on a nonflight day. The reduction of a 50 per cent magnitude from normal is highly significant, and is indicative of adrenal hyperactivity four or five hours earlier. Such subnormal rates have been observed, first in the plasma, then in the urine in stress situations and are shown in the data of Hetzel *et al.*,¹¹ and others.^{5, 16} This explanation would be compatible with the significant changes in leukocytes in the normal subjects mentioned earlier, indicating a stressful situation early in the mission. The L-D subjects under the same conditions had increases in post-exposure excretion rates which were not significant.

When both groups of subjects were exposed to zero gravity plus Coriolis acceleration, corticoid excretion patterns were quite similar to those found in zero-G alone. The normals had significant decreases in output and the L-D's had increases but at a low order of significance. Although there appears to be a clear-cut difference in excretion pattern between the two groups that substantiates the hematological changes as far as stress is concerned, the reason for increase in mean values of the L-D subjects is not clear at this time.

The measure of catechol amine excretion in both groups (Figure 3) was interesting in that changes paralleling corticoid excretion did not occur as it did in a previous experiment where extra G forces and

disorientation were experimental variables.³ Engle⁷ has pointed out that, although adrenal cortical secretion increases after physical stress, the higher levels are not always concomitant with serum epinephrine increases. Conversely, increase in serum epinephrine levels do not always produce elevated corticoid levels.² Furthermore, Elmadjian *et al.*⁶ demonstrated that catechol increments occur with emotional displays, and Mason¹⁶ felt that corticoid increases are related more to distress or distress involvement. The results of this experiment would be in accord with those views. While there were no observations which would indicate that the subjects were occupied with the emotion of fear, distress was evidenced by the fact that the majority of the normals, but not the L-D's, were nauseated by the Coriolis acceleration.⁹

Changes in mean pyruvic and lactic acid concentrations were down (Figure 4) in seven out of eight postflight samples, but the deviations were not significant at the 90 per cent confidence level. Lactic dehydrogenase changes also were not significant. Although there may be an indication in the data that muscle metabolism parameters are affected by the zero gravity state, the length of exposure was perhaps too short to produce pronounced changes.

Table 1 summarizes the confidence levels of the determined values of the experiment. If levels of 0.1 and lower are assumed as significant, it would appear

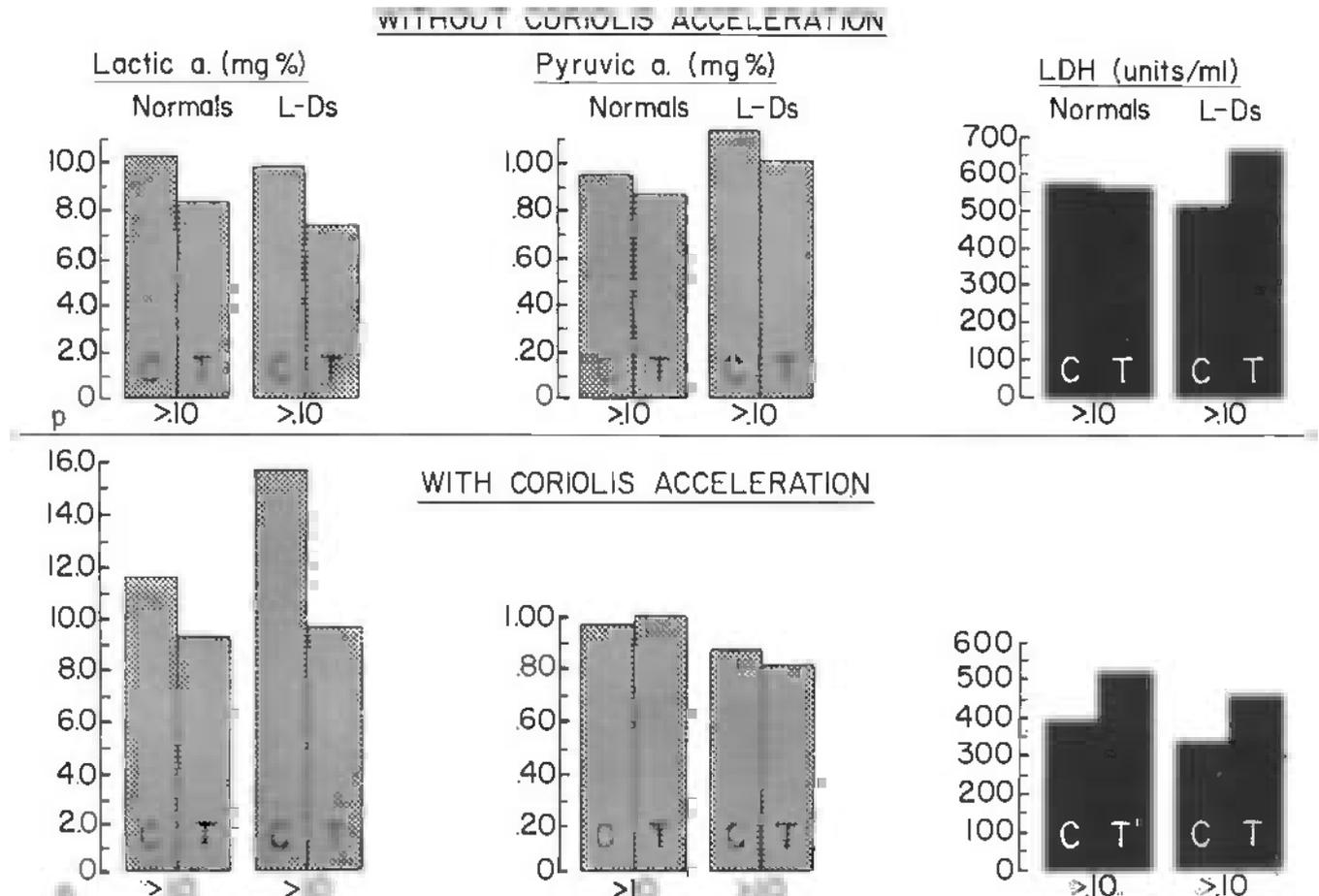


Fig. 4. Changes in biochemical values associated with muscle metabolism after short-term zero gravity flight.

C = Control T = Test

THE EFFECTS OF CORIOLIS ACCELERATION DURING ZERO-GRAVITY PARABOLIC FLIGHT—COLEHOUR

TABLE I. SUMMARY OF CONFIDENCE LEVELS OF BLOOD AND URINARY CHANGES AFTER REPETITIVE ZERO-G FLIGHT
MANN-WHITNEY "P" VALUES *

| | | BLOOD VALUES | | | | | | | URINE VALUES | | | |
|----------|-----------------------|--------------|-------|-------|-------|-----------|--------------|-----|--------------|------|----|------|
| | | WBC | neut. | lymp. | eos. | lac d. | pyruv. d. | LDH | 17-OHS | E | NE | E+NE |
| NORMALS | Zero G | <.02 | <.02 | NS | <.10 | NS | NS | NS | <.005 | NS | NS | NS |
| | Zero G+ Cor.Accel. | <.005 | <.005 | NS | <.002 | NS | NS | NS | <.10 | NS | NS | NS |
| LAB-DEF. | Zero G | NS | NS | NS | NS | NS | NS | NS | NS | <.04 | NS | NS |
| | Zero G+ Cor.Accel. | NS | NS | NS | NS | NS | NS | NS | <.05 | NS | NS | NS |

Confidence levels of greater than .10 considered not significant.
* Auble, D.: *Bull. Inst. Ed. Research at Indiana U.*, Vol 1, No. 2 (1953).

that the normal subjects had leukocytic and corticosteroid changes indicative of stress situations especially when subjected to Coriolis acceleration in the zero gravity state. Labyrinthine defective subjects were not similarly affected by the conditions of the experiment.

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REFERENCES

- BARTTER, F. C., DELEA, C. S., and HALBERG, F.: A map of blood and urinary changes related to circadian variations in adrenal cortical function in normal subjects. *Ann. N. Y. Acad. Sci.*, 98:969, 1962.
- BEST, W. R., KIRK, R. M., MUEHRCKE, R. C., and SAMTER, M.: Clinical value of eosinophil counts and eosinophil response tests. *J. Amer. Med. Ass.*, 151:702, 1953.
- COLEHOUR, J. K., and GRAYBIEL, A.: Excretion of 17-hydroxycorticosteroids, catechol amines, and uropesin in the urine of normal persons and deaf subjects with bilateral vestibular defects following acrobatic flight stress. *Aerospace Med.*, 35:370, 1964.
- CROUT, J. R.: Catechol amines in urine. In Seligson, D. (Ed.): *Standard Methods of Clinical Chemistry*. Vol. 3. New York: Academic Press, 1961.
- DAHL, E. V., FRANKS, J. J., PRIGMORE, J. R., and CRAMER, R. L.: Adrenal cortical response in motion sickness. *Arch. Environ. Health*, 7:92, 1963.
- ELMADJIAN, F., HOPE, J. M., and LAMSON, E. T.: Excretion of epinephrine and norepinephrine under stress. In Pincus, G. (Ed.): *Recent Progress in Hormone Research*. Vol. 14. New York and London: Academic Press, 1958.
- ENGLE, F. M.: General concepts of adrenocortical function in relation to the response to stress. *Psychosom. Med.*, 15:565, 1953.
- GRAYBIEL, A.: Orientation in space, with particular reference to vestibular functions. In Schaefer, K. E. (Ed.): *Environmental Effects of Consciousness*. New York: The Macmillan Company, 1962.
- GRAYBIEL, A., KENNEDY, R. A., and KELLOGG, R. A.: Vestibular (canal) sickness precipitated in the weightless phase of zero-G parabolas by Coriolis force. Presented at the 35th Annual Scientific Meeting, Aerospace Medical Association, Miami Beach, Florida, May 11-14, 1964.
- HALBERG, F.: The 24-hour scale: A time dimension of adaptive functional organization. *Perspectives in Biol. & Med.*, 3:491, 1960.
- HETZEL, B. S., SCOTTSTAEDT, W. W., GRACE, W. J., and WOLFF, H. G.: Changes in urinary 17-hydroxycorticosteroid excretion during stressful life experiences in man. *J. Clin. Endocrin.*, 15:1057, 1955.
- HILLS, A. G., FORSHAM, P. H., and FINCH, C. A.: Changes in circulating leukocytes induced by the administration of pituitary adrenocorticotrophic hormone (ACTH) in man. *Blood*, 3:755, 1948.
- JOHNSON, W., MEEK, J., and GRAYBIEL, A.: Effects of labyrinthectomy on canal sickness in the squirrel monkey. *Ann. Otol. etc., St. Louis*, 71:289, 1962.
- KELLEY, V. C., ELY, R. S., RAILE, R. B., and BRAY, P. F.: Comparison of eosinophil and circulating 17-hydroxycorticosteroid responses to epinephrine and ACTH. *Proc. Soc. exp. Biol., N. Y.*, 81:611, 1952.
- KORNEL, L.: An improved, rapid method for free and conjugated 17-hydroxycorticosteroids in urine. *Metabolism*, 8:432, 1959.
- MASON, J. W.: Psychological influences on the pituitary-adrenal cortical system. In Pincus, G. (Ed.): *Recent Progress in Hormone Research*, Vol. 15. New York and London: Academic Press, 1959.
- MINNERS, H. A., DOUGLAS, W. K., KNOBLOCK, E. C., GRAYBIEL, A., and HAWKINS, W. R.: Aeromedical preparation and results of postflight medical examinations. In *Results of the First United States Manned Orbital Space Flight*, February 20, 1962. National Aeronautics and Space Administration, Manned Spacecraft Center.
- MINNERS, H. A., WHITE, S. C., DOUGLAS, W. K., KNOBLOCK, E. C., and GRAYBIEL, A.: Aeromedical studies. Clinical aeromedical observations. In *Results of the Second United States Manned Orbital Space Flight*, May 24, 1962. NASA SP-6. National Aeronautics and Space Administration, Manned Spacecraft Center.
- NELSON, D. H., SANDBERG, A. A., PALMER, J. G., and TYLER, F. H.: Blood levels of 17-hydroxycorticosteroids following the administration of adrenal steroids and their relation to levels of circulating leukocytes. *Jour. Clin. Invest.*, 31:843, 1952.
- ROCHE, M., HILLS, A. G., and THORN, G. W.: The levels of circulating eosinophils and their response to ACTH in surgery. Their use as an index of adrenal cortical function. In Mote, J. R. (Ed.): *Proceedings of the First ACTH Conference*. Philadelphia and Toronto: The Blakiston Company, 1950.
- SHARP, G. W. G.: Reversal of diurnal leukocyte variations in man. *J. Endocrin.*, 21:107, 1960.
- WROBLEWSKI, F., and LADUE, J. S.: Lactic dehydrogenase activity in blood. *Proc. Soc. exp. Biol., N. Y.*, 90:210, 1955.