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Gravity Measured at the Apollo 14 Landing Site

Abstract. *The gravity at the Apollo 14 landing site has been determined from the accelerometer data that were telemetered from the lunar module. The values for the lunar gravity measured at the Apollo 11, 12, and 14 sites were reduced to a common elevation and were then compared between sites. A theoretical gravity, based on the assumption of a spherical moon, was computed for each landing site and compared with the observed value. The observed gravity was also used to compute the lunar radius at each landing site.*

The results of measuring the magnitude of the gravity vector on the lunar surface at the Apollo 11 and 12 landing sites have been reported (*1*). A third gravity measurement has been made at the Apollo 14 landing site. The observed gravities at the three landing sites are listed in Table 1.

Gravity was reduced from the accelerometer data telemetered from the lunar module (LM) primary guidance, navigation, and control systems. The method used to determine gravity for the Apollo 11 and 12 missions has been described (*1*).

A new procedure was used to determine gravity during Apollo 14. This procedure was initiated after the LM's position on the lunar surface was determined by means of rendezvous radar measurements to the command module (CM) in lunar orbit. The x-accelerometer was rotated to a vertical attitude, and accelerometer data ($-x$) were telemetered for time T_1. The x-accelerometer was then "turned upside down." That is, the accelerometer was rotated 180 degrees until it was in the vertical attitude again. Then accelerometer data ($+x$) were telemetered for time T_2. According to this procedure, the observed gravity g was computed from $g = \frac{1}{2}[(-x/T_1) - (x/T_2)]$ (scale factor), where the scale factor was determined before launch. This procedure gave an increased confidence in the accuracy of the observed gravity at the Apollo 14 landing site.

Table 1. Observed gravity g, free air correction $g_f h$, observed gravity reduced to a 1736-km radius g_0, theoretical gravity g_1, and gravity anomaly Δg (mgal).

Quantity	Gravity (mgal)		
	Apollo 11	Apollo 12	Apollo 14
g	162,852	162,674	162,653
$g_f h$	−100	0	74
g_0	162,752	162,674	162,727
g_1	162,783	162,683	162,610
$\Delta g = g - g_1$	69	−9	43

Although the lunar gravity field is only one-sixth the earth's gravity field, lunar gravity still changes rapidly with changes in the elevation of the observation point. Because lunar gravity is sensitive to elevation, the observed gravity should be reduced to some common elevation before gravity is compared between sites. Therefore, all the gravity observations were reduced to a radius of 1736 km, which is approximately the mean of the lunar radii at the three Apollo landing sites. The reduced gravity g_0 was computed from $g_0 = g - g_f h$. The free air correction g_f is given by $g_f = \delta g/\delta R = 2GMR^{-3}$, where GM is the product of the gravitational constant G and the lunar mass M, and R is the radius at the observation point. The value used for GM is 4902.78 km^3 sec^{-2} (*2*). If the mean value, 1736 km, is used for R, the value obtained for g_f is 187.6 mgal/km. The elevation h at each site is the difference between the lunar radius at the site, R_T, and the mean radius. For the Apollo 11, 12, and 14 landing sites, the best values of R_T were determined from the lunar orbit of the CM and the altitude of the CM in orbit above the LM on the lunar surface. The CM's lunar orbits were determined by Doppler tracking of the CM from stations on the earth. The altitudes were determined by rendezvous radar tracking of the LM on the lunar surface from the CM in lunar orbit. The elevations h and the landing site radii R_T from tracking data are listed in Table 2, and values of $g_f h$ are listed in Table 1. The differences between the values of reduced gravity for the Apollo sites are: for 11 − 12, +78 mgal; for 11 − 14, +25 mgal; and for 12 − 14, −53 mgal.

The observed gravity should be quantitatively compared with the theoretical gravity g_1 at the observation point. If the moon is assumed to be spherical, the theoretical gravity can be computed from $g_1 = GM/R_T^2$. A gravity anomaly is defined here as the difference between the observed gravity and the theoretical gravity, that is, $\Delta g = g - g_1$. Values of the theoretical gravity and the gravity anomalies at the Apollo 11, 12, and 14 sites are listed in Table 1.

If it is assumed that the moon is a sphere, the lunar radius R_g at each landing site can be computed from $R_g = (GM)^{1/2} g^{-1/2}$. This method of computing the lunar radius is independent of all data other than GM and g. The R_g values for the Apollo 11, 12, and 14 landing sites are listed in Table 2.

It is interesting that the values of R_g agree so well with the values of R_T. The root-mean-square value of R_T differs from that of R_g by only 0.18 km

Table 2. Apollo 11, 12, and 14 lunar radius values and elevations. The radii from tracking data are denoted by R_T, those calculated from the observed gravity by R_g, and those from earth-based data (*3*) by R_e. The elevations at the sites are given as h. The r.m.s. for each quantity is its root-mean-square value.

Item	Radius (km)			
	Apollo 11	Apollo 12	Apollo 14	r.m.s.
R_T	1735.47	1736.00	1736.39	1735.95
h	−0.53	0	+0.39	
R_g	1735.10	1736.05	1736.16	1735.77
R_e	1738.40	1738.60	1738.30	1738.43

(see Table 2). Both R_g and R_T, which are obtained from spacecraft data, seem to be systematically smaller than the radii R_e obtained from what is probably the best earth-based data (*3*). The root-mean-square value of R_e is approximately 2.5 km larger than that of both R_g and R_T. The Ranger and Orbiter data (*4*) also seem to be systematically 2.5 km smaller than earth-based data.

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Brain Serotonin Content: Increase Following Ingestion of Carbohydrate Diet

Abstract. *In the rat, the injection of insulin or the consumption of carbohydrate causes sequential increases in the concentrations of tryptophan in the plasma and the brain and of serotonin in the brain. Serotonin-containing neurons may thus participate in systems whereby the rat brain integrates information about the metabolic state in its relation to control of homeostatis and behavior.*

The concentration of serotonin, a putative neurotransmitter in the mammalian central nervous system, varies as a result of physiological changes in the availability of its precursor, tryptophan (*1, 2*). Large parenteral doses of tryptophan rapidly increase the amount of serotonin in the brain (*3*). Increases (*4*) or decreases (*5*) in dietary tryptophan over several weeks or more are associated with parallel alterations in brain serotonin. Tryptophan concentrations in plasma and brain (*1, 2, 6*) and serotonin concentrations in brain (*7*) undergo characteristic daily variations. If rats are injected with small amounts of tryptophan (less than one-twentieth of their daily dietary intake) at the time of day when tryptophan concentrations in the brain and plasma are lowest, the serotonin in the brain increases within about an hour (*2*). Brain tryptophan also increases, but remains within the normal daily range (*6*). The foregoing observations suggest that naturally occurring changes in plasma tryptophan (for example, in response to diet) could "drive" brain tryptophan concentrations, and that changes in the latter could, in turn, affect brain serotonin.

Administration or secretion of insulin lowers the concentrations of glucose and of most amino acids in the plasma (*8, 9*). In contrast, tryptophan in plasma *increases* in rats injected with insulin or given access to a carbohydrate diet (*9*). Thus it might be anticipated that insulin would also increase the concentrations of brain tryptophan, and, ultimately, of serotonin. Very high doses of insulin have been shown to elevate brain serotonin concentrations (*10*); however, because these doses also produced convulsions, the change in brain serotonin could have been due to abnormal neuronal activity, and not to enhanced concentration of tryptophan in the brain.

We now show that in rats the increase in plasma tryptophan after ingestion of carbohydrate or after injection of subconvulsive doses of insulin is accompanied by parallel increases in the concentrations of tryptophan and serotonin in the brain.

Male Sprague-Dawley rats (Charles River Laboratories) were housed five per cage, exposed to light (*11*) from 9 a.m. to 9 p.m. daily, and given free access to food (Big Red Laboratory Animal Chow, Agway) and water. At 9 p.m. on the evening before an experiment the rats were placed in clean cages and deprived of food. Between noon and 3 p.m. the next day, groups of seven animals were injected intraperitoneally with insulin (2 units of Iletin per kilogram of body weight, 40 unit/ml) diluted in water. During this interval other uninjected groups of ten animals were given free access to a protein-free diet composed largely of carbohydrates (*12*). Rats were decapitated 1, 2, or 3 hours after injection or exposure to the diet, and blood from the cervical wound was collected in heparinized tubes and centrifuged. Plasma was frozen and subsequently assayed for tryptophan (*13*), tyrosine (*14*), and glucose (*15*). The brains were quickly removed, bisected midsagittally, and frozen on Dry Ice. One-half of each brain was assayed for tryptophan (*13*), and the other half was assayed for serotonin (*16*). In no case did the levels of compounds measured in control animals at 1, 2, or 3 hours after the start of an experiment differ from those at zero time. Hence all comparisons between control and insulin-treated rats were made with the zero-time control group as base.

As shown earlier (*9*), plasma tryptophan concentrations in rats receiving insulin were increased by 40 percent as compared to those of control animals ($P < .01$) 2 hours after injection

Table 1. Effect of carbohydrate ingestion on brain serotonin concentrations and on plasma and brain tryptophan. Plasma amino acid concentrations are in micrograms per milliliter. Brain tryptophan and serotonin concentrations are in micrograms per gram of brain, wet weight. The average animal weight in experiment 1 was 160 g. The average animal weight in experiment 2 was 260 g.

Time after presentation of food (hours)	Tryptophan		Serotonin in brain (μg/g)	Tyrosine in plasma (μg/ml)
	Plasma (μg/ml)	Brain (μg/g)		
		Experiment 1		
0	10.86 ± 0.55	6.78 ± 0.40	0.549 ± 0.015	13.03 ± 0.29
1	13.56 ± 0.81*	8.32 ± 0.63†	0.652 ± 0.046	9.55 ± 0.34‡
2	14.51 ± 0.70‡	11.24 ± 0.52‡	0.652 ± 0.012‡	8.67 ± 0.26‡
3	13.22 ± 0.65*	9.81 ± 0.50‡	0.645 ± 0.017‡	9.03 ± 0.21‡
		Experiment 2		
0	15.09 ± 0.39	3.32 ± 0.16	0.60 ± 0.01	14.23 ± 0.66
1	15.79 ± 0.49	4.70 ± 0.12‡	0.75 ± 0.01‡	10.69 ± 0.23‡
2	16.65 ± 0.52†	5.77 ± 0.09‡	0.76 ± 0.01‡	10.06 ± 0.24‡
3	15.26 ± 0.50	6.29 ± 0.21‡	0.76 ± 0.02‡	11.17 ± 0.40‡

* $P < .02$ differs from zero-time group; † $P < .05$ differs from zero-time group; ‡ $P < .001$ differs from zero-time group.