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United States Air Force

School of Aviation Medicine

Project Report

STUDY OF ACCLIMATIZATION DURING A TWO-WEEK EXPOSURE TO MODERATE ALTITUDE (10,000 FEET)

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[illegible] OF ACCLIMATIZATION DURING A TWO-WEEK EXPOSURE TO MODERATE ALTITUDE (10,000 FEET).

EFFECT OF ALTITUDE ADAPTATION ON NIGHT VISION AND OCULAR MUSCLE BALANCE,

10 H.W. Rose, ~~M.D.~~

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Project Number 21-02-029
Report Number 1

USAF SCHOOL OF AVIATION MEDICINE
RANDOLPH FIELD, TEXAS
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PRECIS

OBJECT:

To investigate the influence that high altitude acclimatization exerts on night vision and on the equilibrium of the ocular muscles.

SUMMARY AND CONCLUSIONS:

Nine to twelve subjects have been examined before, during, and after staying two weeks at an altitude of 3,000 m. (10,000 ft.). The twilight visual acuity, which after a short stay at a simulated high altitude in the decompression chamber shows a marked decline, is restored to normal within 24 hours at actual altitudes of about 2,000 to 3,000 m. (6,500 to 10,000 ft.). This normal value was maintained throughout the following two weeks sojourn at this altitude. The brightness threshold in night vision was likewise restored to normal or better values after staying 24 hours at actual altitudes of about 2,000 to 3,000 m. (6,500 to 10,000 ft.) ---in contrast to the deterioration observed in decompression tests. In those cases where the improvement was above the normal values, a recession was observed during the two weeks period at these altitudes. The examination of the ocular muscle balance *after the first* 24 hours revealed a tendency to *esophoria*, which in the course of the following two weeks at high altitude shifted to a tendency to *exophoria*. These processes, depending on the extent and moment of their manifestations, may gain importance in long distance flights. They may be induced in pressure cabin aircraft in which the prevailing pressure is less than that at ground level.

RECOMMENDATIONS:

Because of the preliminary nature of these investigations, it is suggested that further acclimatization tests be made to determine more accurately the moment of manifestation of the phenomena described. The information thus obtained should be applied in the flier's indoctrinations and in the planning of night missions. The knowledge of the changes in muscle balance should be considered in the compilation of fitness regulations.

EFFECT OF ALTITUDE ADAPTATION ON NIGHT VISION AND OCULAR MUSCLE BALANCE

INTRODUCTION

Some ocular functions, especially twilight and night vision, are sensitive indicators of oxygen deficiency. The behavior of these functions under acute hypoxia has been the object of numerous investigations. However, it has not yet been clarified as to what changes the ocular functions are subjected under prolonged oxygen deficiency. Increased cardiac and circulatory activities are the first phenomena of high altitude acclimatization. Later, the predominant factor is the increase in the hemoglobin content of the blood. This latter phenomenon even outlasts the sojourn at high altitudes by several weeks. In these phenomena of high altitude acclimatization, the eye---like other organs---is only the indicator and effector organ. Whether significant acclimatization processes occur in the organ or the tissue has not been sufficiently clarified. The oxygen need of different organs, well-developed measuring methods, and the importance of the ocular functions for the altitude-acclimatized flier justify the ophthalmologist's interest in examining the eye during high altitude acclimatization.

METHOD

Since our examinees for the high altitude acclimatization tests served at the same time as subjects for a series of other, mainly physiologic examinations, and since they themselves were frequently in charge of other tests, a compromise as to the procedure of the ophthalmologic investigations was necessary. The 15 test subjects requested for the test could not be made available within the schedule of the altitude tests; therefore, their number was reduced to 12. From these 12 subjects, several men for various reasons had to discontinue the test so that for most of the examinations described complete measurements were obtained on a series of 9 or 10 persons. The apparatus available for these tests had a decisive influence on the choice of the test procedure. The night vision tests were planned to comprise investigations on the twilight visual acuity, on the night visual acuity, and on the brightness thresholds in night vision. The night visual acuity could not be tested because the two available pieces of apparatus failed in their shutter mechanism.

The twilight visual acuity was examined by means of the Comberg[1,2] nyktometer. Detailed description of the apparatus and method are found in previous reports of the author[3]. In the beginning of this test the examinee remains 30 minutes in a faintly illuminated room; then follows three minutes of adaptation to a brightness of 3,000 apostilb*. After this bright light is switched off, the visual acuity is measured during the following two minutes at 0.5 apostilb. At first, the visual acuity shows a rapid increase which is nearly complete in about two minutes. Since this kind of examination involves considerable training effect, the first two tests of every examinee were not evaluated.

The night visual thresholds were measured with an Engelking-Hartung adaptometer. This examination was preceded by an adaptation period of 30 minutes with red goggles. Then followed ten minutes of brightness adaptation to 3,000 apostilb by means of Ulbricht's sphere. For the stimulation, the adaptometer is provided with an

*1 apostilb = $\frac{1 \text{ new candle}}{\pi \cdot 10^4 \cdot \text{cm}^2} \approx 10^2$ micro lambert.

opal glass disc of 10 cm. in diameter, which the examinee views from a distance of 40 cm. The subtended angle of the object is then 15°. Ten centimeters (15°) above the upper edge of the test object is a deep red fixation point. The brightness of the stimulus could be varied between 1.2×10^{-2} μasb.* and 2.2×10^{5} μasb. The examinee himself adjusted the brightness of the stimulus and performed the individual measurements by increasing the brightness until he could perceive the light (appearance threshold). Measuring the vanishing threshold (the decrease of brightness of the stimulus to the vanishing point) is difficult because of after images and adjustment difficulties. It is the author's opinion that this method is less accurate than that of measuring the appearance threshold.[3] In all tests the threshold measurements were taken 2, 5, 10, 15, 20, 25, and 30 minutes following the brightness adaptation.

The first dark adaptation test of each subject examined, being an informative test, was not evaluated. In this method of measuring thresholds the training effect is usually less than in those methods which include a visual acuity examination. The nyktometer and the adaptometer were checked before and after the test by means of a photometer which was carefully calibrated in new candles. A measurable deviation in the brightness of the apparatus during the examinations was not apparent. The electric current in the nyktometer and the adaptometer was continuously controlled by precision instruments. In addition, a voltage stabilizer was interconnected between circuit and adaptometer.

Heterophoria was measured from a distance of six meters (20 ft.) with red Maddox rods and a Herschel rotary double prism, (manufacturer: Carl Zeiss, Jena). This prism is calibrated in prism diopters. With the same prisms the range of fusion, the power of abduction and the power of adduction for a distance of six meters were measured. For each examination of heterophoria, three readings were made with our apparatus. The first one was not evaluated. The other two readings were averaged. For each examination of the adduction and abduction power two readings were made and the mean values computed.

*1 microapostilb ≈ 10^{2} micro micro lambert.

The examinations of twilight visual acuity and night visual threshold were made at Randolph Field (232 m. (761 ft.) alt.) from 10 to 13 June 1947. They were performed twice on every test subject after identical training tests.

The examination of heterophoria and fusion range, because of lack of time, was carried only once, on 18 June 1947, at Randolph Field. On the morning of 19 June 1947, all test subjects were flown to Colorado Springs. In the afternoon they were driven by automobile to Leadville, Colorado, (3,096 m. (10,152 ft.) alt.) for high altitude acclimatization. There a full series of measurements of twilight visual acuity, night visual threshold, heterophoria, and range of fusion were made on 20, 22, 24, 28, and 30 June. Until 28 June none of the test subjects made excursions into much higher regions. Over the weekend of 28-29 June the majority of the test subjects participated in an excursion to an altitude of 4,400 m. (14,430 ft.). On 4 July, after having remained at Leadville for two weeks, the group started on their return journey.

On 10 and 11 July each test subject was again given the full series of measurements described, this time, however, in the decompression chamber at Randolph Field. The low pressure corresponded to an altitude of 3,100 m. (10,165 ft.) i.e., practically equal to that of Leadville. In August and September 1947, the same tests were repeated on the same test subjects; once under the normal atmospheric pressure of Randolph Field and once in the decompression chamber (under low pressure corresponding to 3,100 m. (10,165 ft.)). For each test subject the latter two examinations were performed the same day. Because of the difficulties in getting the requested test subjects for these examinations, there is a considerable scatter of the examination data. This scatter was tolerated because of the assumption that by that time the high altitude acclimatization effect would have vanished.*

*During the stay at Leadville the tests were carried out by the author, Capt. William Patterson, and Sgt. G.B. Johanson. The examinations at Randolph Field were done by the author and Miss E. Freytag. The altitude sojourn was organized by Col. Donald D. Flickinger and Capt. Patterson.

RESULTS

In the presentation of the results we have designated the individual test series with the following symbols:

RC_1 = first control measurement at Randolph Field, 10 to 13 June 1947.

RC_2 = second control measurement at Randolph Field, 10 to 13 June 1947.

L_1 = examination in Leadville, 20 June 1947.

L_2 = examination in Leadville, 22 June 1947.

L_3 = examination in Leadville, 24 June 1947.

L_4 = examination in Leadville, 28 June 1947.

L_5 = examination in Leadville, 30 June 1947.

Rl_1 = first examination in decompression chamber after return to Randolph Field, 10 to 11 July 1947.

R = examination at ground level, Randolph Field, August to September, 1947.

Rl_2 = second examination in decompression chamber after return to Randolph Field, August to September, 1947

In all illustrations, with the exception of figure 6, the abscissas show varying time scales. All RC tests in which the ocular muscle balance was examined were carried out on the same day. All measurements at Leadville which constitute one point of the curve, were carried out on the same day. All other points of the curve are derived from measurements taken on various days. In my opinion, doubts as to the homogeneity of the respective measurements are not justified. Figure 1 shows the results of examination with

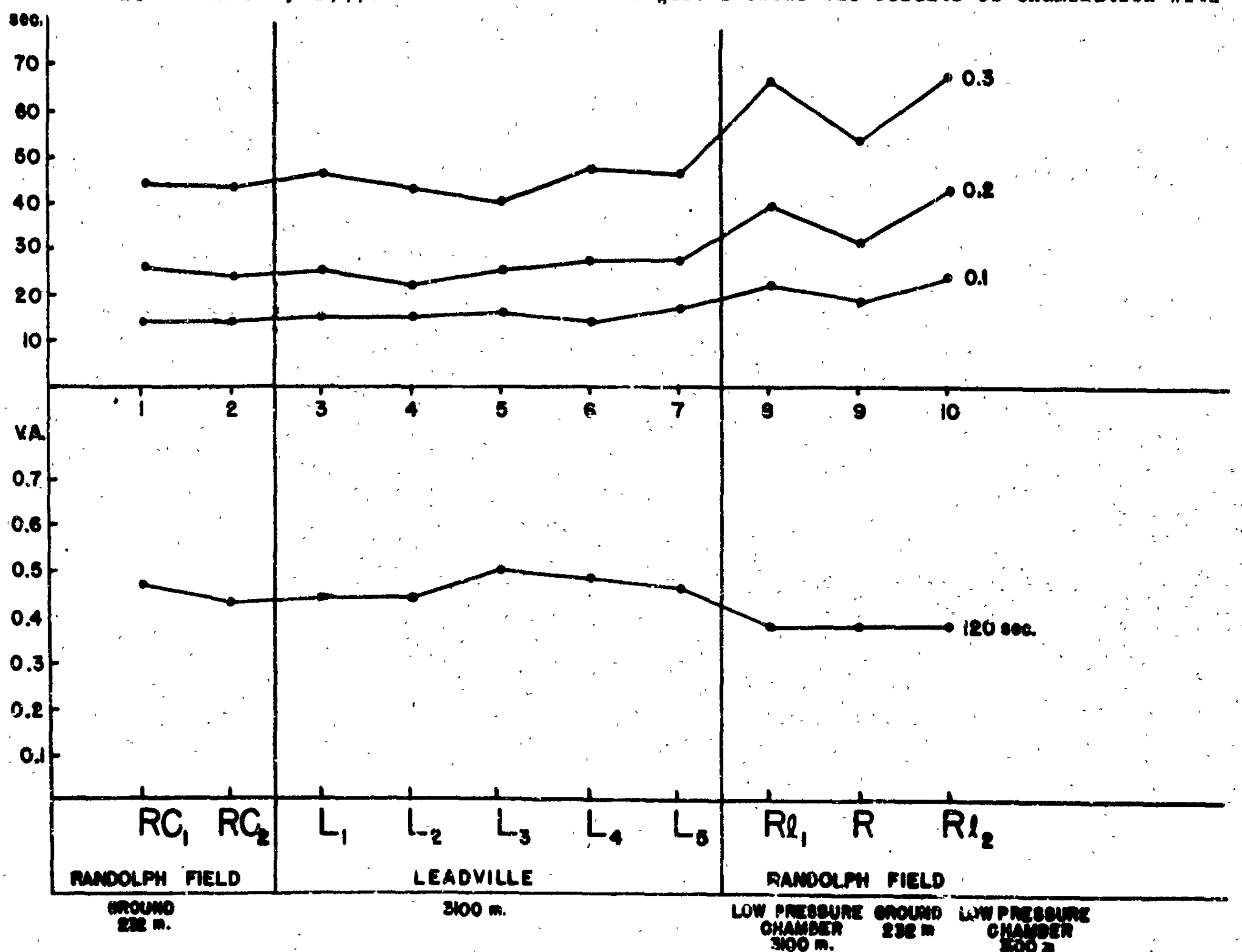

FIGURE 1
Mean values of twilight visual acuity of 9 subjects, tested with the nyktometer.

TABLE 1
Twilight Visual Acuity
Mean Values of Measurement on 9 Subjects

		Test Days									
		RC_1	RC_2	L_1	L_2	L_3	L_4	L_5	Rl_1	R	Rl_2
Seconds to Reach Visual Acuity:	0.1	13.8	13.6	14.6	14.9	15.7	14.3	17.2	22.4	19.1	24.1
	0.2	25.7	24.1	25.4	22.8	25.4	26.9	27.4	38.6	30.6	42.0
	0.3	43.8	42.8	46.1	42.6	40.4	46.9	45.7	65.6	52.8	67.2
Visual Acuity After 120 Seconds		0.47	0.43	0.44	0.44	0.50	0.48	0.46	0.38	0.38	0.38

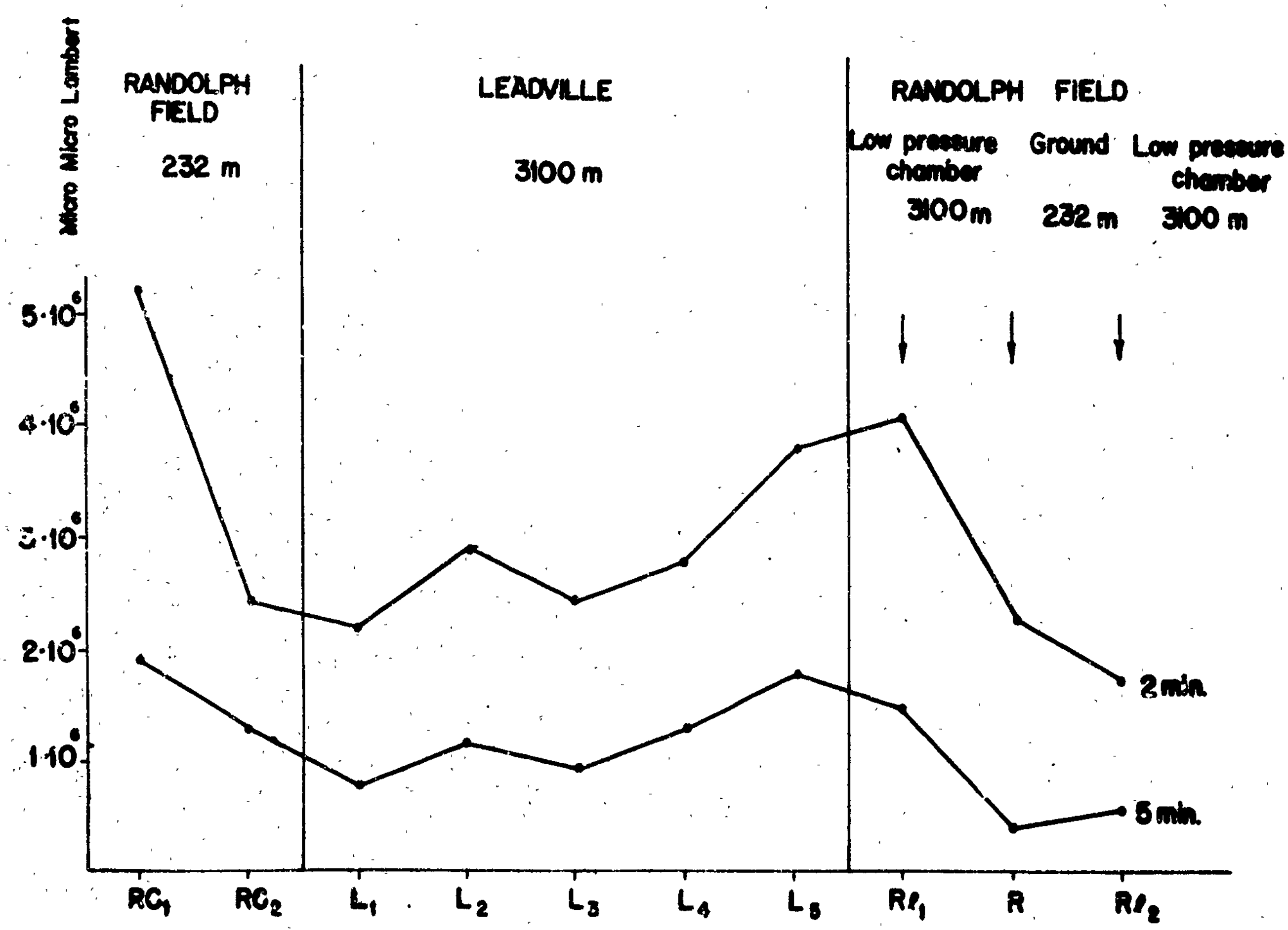

FIGURE 2
Mean values of night vision thresholds of 10 subjects 2 minutes and 5 minutes after the beginning of dark adaptation.

TABLE 2
Statistical Evaluation of Tests of Twilight Visual Acuity

		Compared Tests			
		$\frac{RC_1 + RC_2}{2}$ vs. L_1	L_1 vs. $\frac{L_4 + L_5}{2}$	$\frac{L_4 + L_5}{2}$ vs. Rl_1	R vs. Rl_2
Time Required to Reach Visual Acuity 0.1	Observed Difference	0.9	1.2	6.6	5.0
	$P(I)$	> 0.30	> 0.30	0.012	0.09
	$P(II_{0.05})$		9.5		10.9
	$P(II_{0.01})$		11.4		13.2
	$P(II_{0.0027})$		11.5		13.3
Time Required to Reach Visual Acuity 0.2	Observed Difference	0.5	1.8	11.4	11.4
	$P(I)$	> 0.30	> 0.30	0.0058	0.016
	$P(II_{0.05})$		15.0		17.3
	$P(II_{0.01})$		18.0		20.8
	$P(II_{0.0027})$		18.2		21.0
Time Required to Reach Visual Acuity 0.3	Observed Difference	2.8	0.2	19.3	14.4
	$P(I)$	> 0.30	> 0.30	0.0038	0.05
	$P(II_{0.05})$		22.3		25.8
	$P(II_{0.01})$		26.8		31.0
	$P(II_{0.0027})$		27.2		31.4
Visual Acuity After 120 sec.	Observed Difference	0.01	0.03	0.09	0
	$P(I)$	> 0.30	> 0.30	< 0.0027	1.0
	$P(II_{0.05})$		0.08		0.09
	$P(II_{0.01})$		0.10		0.11
	$P(II_{0.0027})$		0.10		0.11

$P(II_{0.05})$ here means the minimum difference for a $P(II) = 0.05$ when the level of significance of $P(I)$ is 0.05.

$P(II_{0.01})$ here means the minimum difference for a $P(II) = 0.05$ when the level of significance of $P(I)$ is 0.01.

$P(II_{0.0027})$ here means the minimum difference for a $P(II) = 0.05$ when the level of significance of $P(I)$ is 0.0027.

TABLE 3
Examination of Night Vision
(Mean Values of 10 Subjects. Brightness Given in Micromicrolamberts)

	Test Days									
Min	RC_1	RC_2	L_1	L_2	L_3	L_4	L_5	Rl_1	R	Rl_2
2	$5.20 \cdot 10^6$	$2.42 \cdot 10^6$	$2.19 \cdot 10^6$	$2.92 \cdot 10^6$	$2.42 \cdot 10^6$	$2.81 \cdot 10^6$	$3.78 \cdot 10^6$	$4.06 \cdot 10^6$	$2.29 \cdot 10^6$	$1.77 \cdot 10^6$
5	$1.93 \cdot 10^6$	$1.28 \cdot 10^6$	$0.77 \cdot 10^6$	$1.16 \cdot 10^6$	$0.92 \cdot 10^6$	$1.29 \cdot 10^6$	$1.77 \cdot 10^6$	$1.46 \cdot 10^6$	$0.42 \cdot 10^6$	$0.58 \cdot 10^6$
10	47550	61000	19120	38700	29600	44250	113000	73200	22940	24740
15	13660	10310	8080	11500	9300	12150	13890	15970	6380	8850
20	9430	6870	4860	5400	4900	8470	8360	9090	4060	7490
25	5520	4530	3620	5400	4600	8390	7090	6760	3430	4820
30	4880	4600	3560	4000	3300	5270	5940	6000	2520	5200

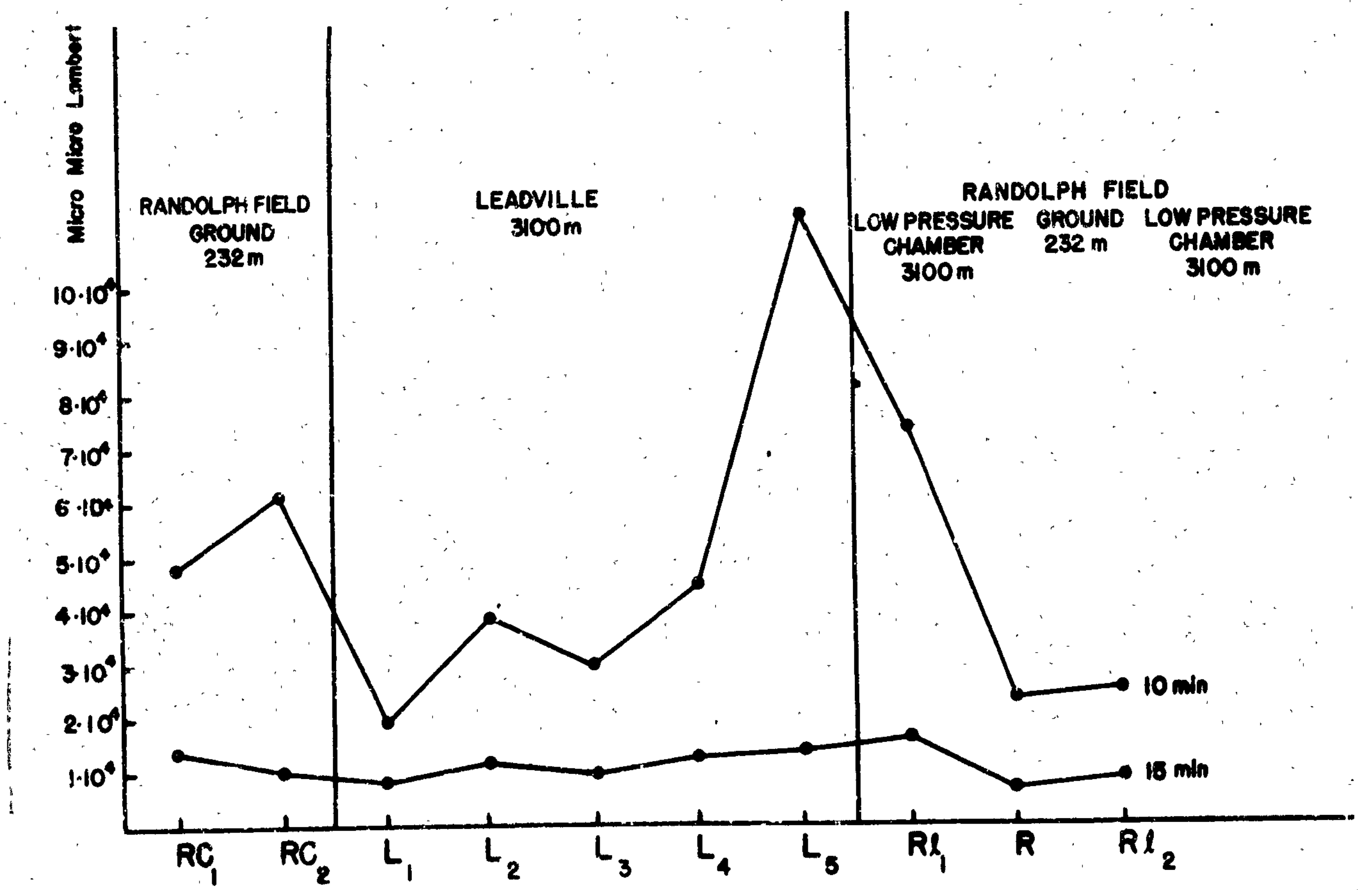

FIGURE 3
Mean values of night vision thresholds of 10 subjects 10 minutes and 15 minutes after the beginning of dark adaptation.

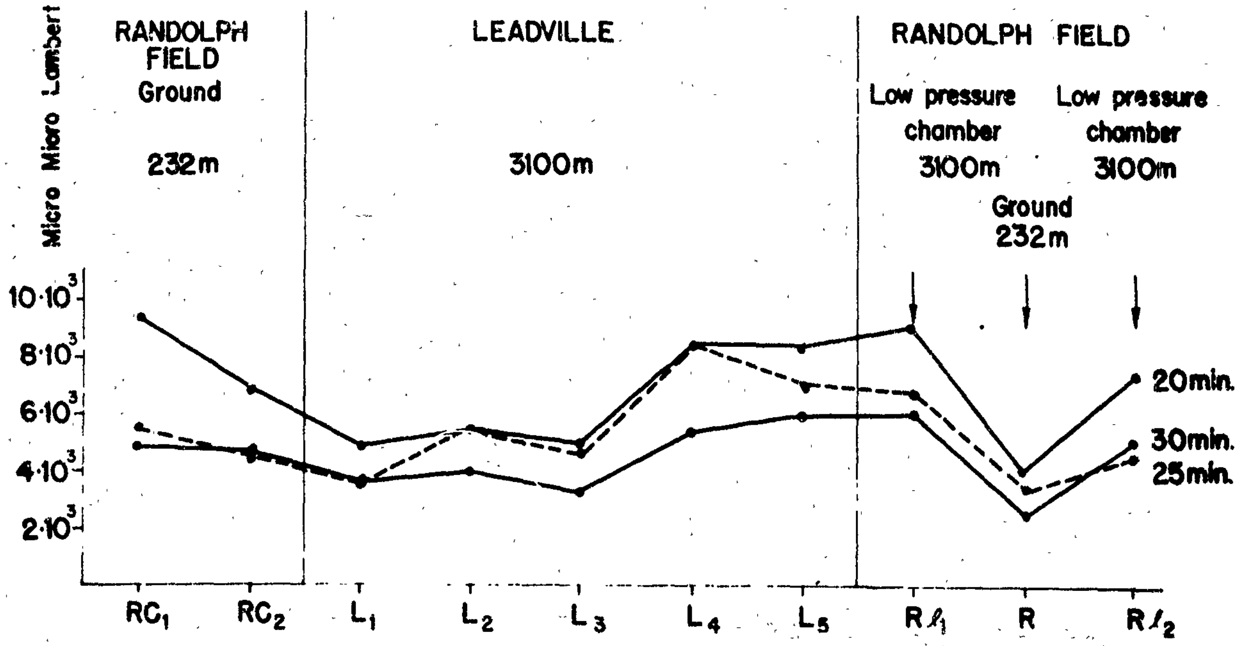

FIGURE 4
Mean values of night vision thresholds of 10 subjects 20 minutes, 25 minutes, and 30 minutes after the beginning of dark adaptation.

the nyktometer (mean values of 9 subjects). The curve with the designation *120 sec.* indicates the decimal value of the visual acuity obtained at the end of the nyktometer test. Since this test is made at a distance of 25 cm., the decimal indication is especially clear for comparison. The upper three curves of figure 1 indicate the time in seconds required for obtaining a certain visual acuity (0.1, 0.2, and 0.3). The numerical values pertaining to the nyktometer test are given in table 1. Because of the essentially even pattern of the curves, a statistical evaluation of the differences seemed valuable for only individual sections of the curves. They were chosen under consideration of the results of all the tests discussed in this report; the testing days, which are statistically compared, are the same for the three groups of tests. Table 2 gives the results of the statistical evaluation*. P(I) in table 2 (and tables 4 and 6) indicates the probability of an error of the first kind, *i.e.*, the probability to discard the so-called zero hypothesis that the true means are equal when in reality they are equal. P (II), the probability of an error of the second kind, indicates the probability that the zero hypothesis is accepted, when the true means are unequal. Since P (II) depends on the level of significance for P (I), the minimum differences in the true means which would be required to make P (II) $\leq$ 0.05 are given for three values of a significance level for P (I), 0.05, 0.01, and 0.0027. The results of measuring the night vision threshold with the adaptometer are compiled in table 3 and figures, 2, 3, and 4. The curve with the designation *2 min.* represents the mean values of 10 test subjects two minutes after starting the dark adaptation. The night vision threshold was measured (designated on the abscissa) on the same days as the twilight visual acuity. The ordinate indicates the brightness in micro micro lambert. Some individuals strongly deviate from the aforementioned mean values, not only quantitatively, but also in the pattern of their curves.

*Statistical results in tables 2, 4, and 6 were computed by Mr. Allyn W. Kimball of the Department of Biometrics, USAF School of Aviation Medicine, Randolph Field, Texas.

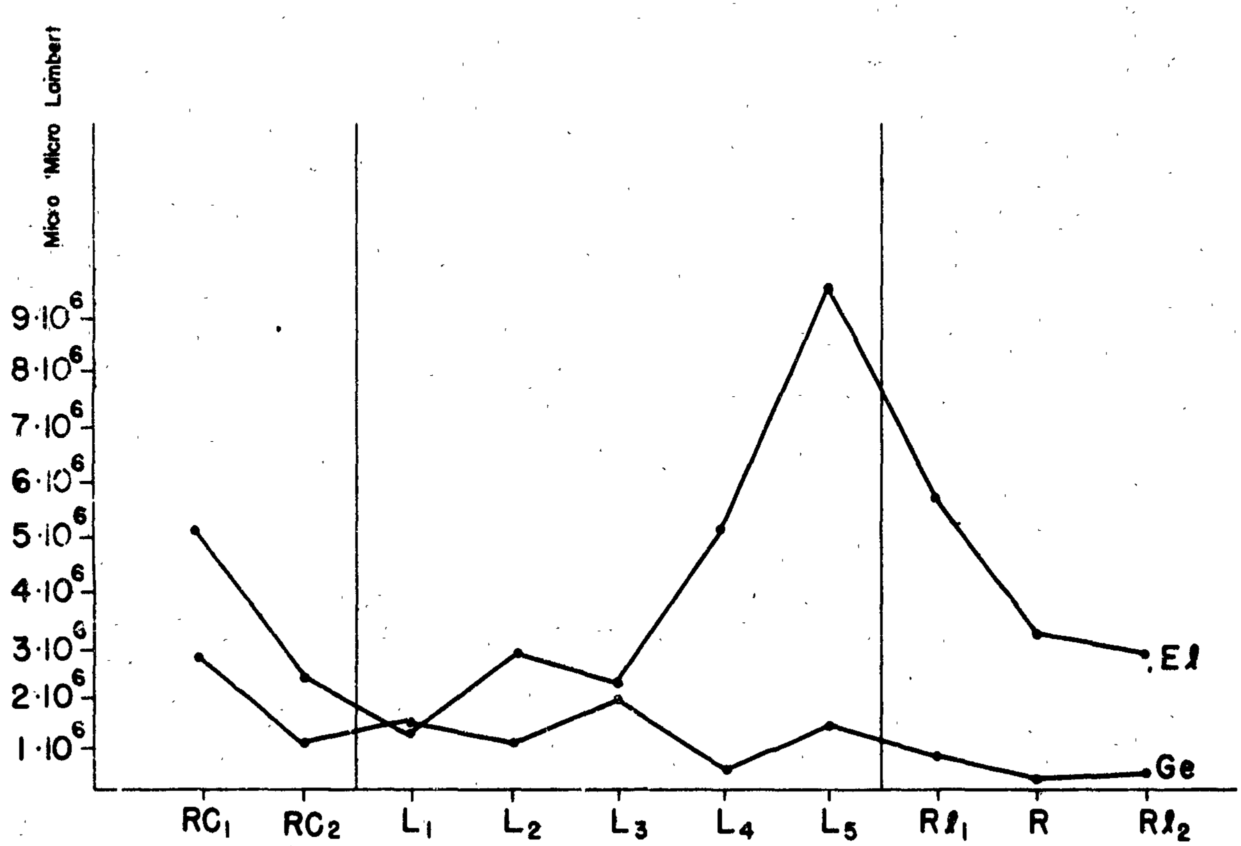

FIGURE 5
Individual differences in the change of night vision thresholds with high altitude acclimatisation. Threshold brightness after 2 minutes dark adaptation of subjects El and Ge..

Figure 5, for example, gives individually the 2 *min.* values of the night visual threshold for two test subjects. Table 4 contains the statistical evaluation of the night visual thresholds. For 2 *min.* the value of RC_1 and for 10 *min.* the values of RC_2 and L_5 were not taken. The significance of P (I) and P (II) has been explained previously.

Figure 6 gives a comparison of the control measurements taken at Randolph Field prior to the sojourn at high altitude (RC_1 and RC_2) with the examinations of the night visual threshold during the sojourn at high altitudes (L_1 to L_5).

The measurements of the muscle balance are contained in table 5 and figures 7,8, and 9. The ordinates uniformly indicate prism diopters. The statistical evaluation, in conformity with the aforementioned methods, is given in table 6. In addition the margins of error (according to methods of S. Koller[4]) have been plotted on the curves representing the mean values.* The margin of error is obtained by adding or subtracting in accordance with the degree of freedom the changing multiples of the standard error of the mean value. The probability for an error remains constant even if the number of test subjects (or the degrees of freedom) change, namely, 0.0027.

DISCUSSION

The usual examinations of the twilight visual acuity in the short decompression chamber test (about 1 hr.) yield for an altitude of 3,000 m. (about 10,000 ft.) slight but well established

*Computed by Miss E. Freytag, USAF School of Aviation Medicine.

TABLE 4
Statistical Evaluation of Night Vision Threshold Tests

		$\frac{RC_1 + RC_2}{2}$ vs. L_1	L_1 vs. $\frac{L_4 + L_5}{2}$	$\frac{L_4 + L_5}{2}$ vs. Rl_1	R vs. Rl_2
2 Min.	Observed Difference	2230	11020	7660	5160
	P(I)	> 0.30	0.012	0.074	> 0.30
	$P(II_{0.05})$	31700	27500		31700
	$P(II_{0.01})$	38200	33100		38200
	$P(II_{0.0027})$	38600	33400		38600
5 min.	Observed Difference	8380	7630	1830	1640
	P(I)	0.056	0.068	> 0.30	> 0.30
	$P(II_{0.05})$		16500		19000
	$P(II_{0.01})$		19800		22900
	$P(II_{0.0027})$		20100		23200
10 min.	Observed Difference	284.3	251.3	289.5	18.0
	P(I)	0.19	0.25	0.18	> 0.30
	$P(II_{0.05})$			807	
	$P(II_{0.01})$			972	
	$P(II_{0.0027})$			983	
15 min.	Observed Difference	39.0	49.4	29.5	24.6
	P(I)	0.067	0.017	0.15	0.30
	$P(II_{0.05})$		76		88
	$P(II_{0.01})$		92		106
	$P(II_{0.0027})$		98		107
20 min.	Observed Difference	32.9	35.6	13.5	34.1
	P(I)	0.031	0.020	> 0.30	0.05
	$P(II_{0.05})$		56		64
	$P(II_{0.01})$		67		78
	$P(II_{0.0027})$		68		79
25 min.	Observed Difference	14.0	41.2	9.8	13.9
	P(I)	0.13	< 0.0027	0.30	0.20
	$P(II_{0.05})$		35		40
	$P(II_{0.01})$		42		48
	$P(II_{0.0027})$		43		49
30 min.	Observed Difference	11.8	20.4	4.0	26.8
	P(I)	0.22	0.086	>0.30	0.017
	$P(II_{0.05})$		36		41
	$P(II_{0.01})$		43		50
	$P(II_{0.0027})$		44		51

For the meaning of P(II) see footnotes to table 2.

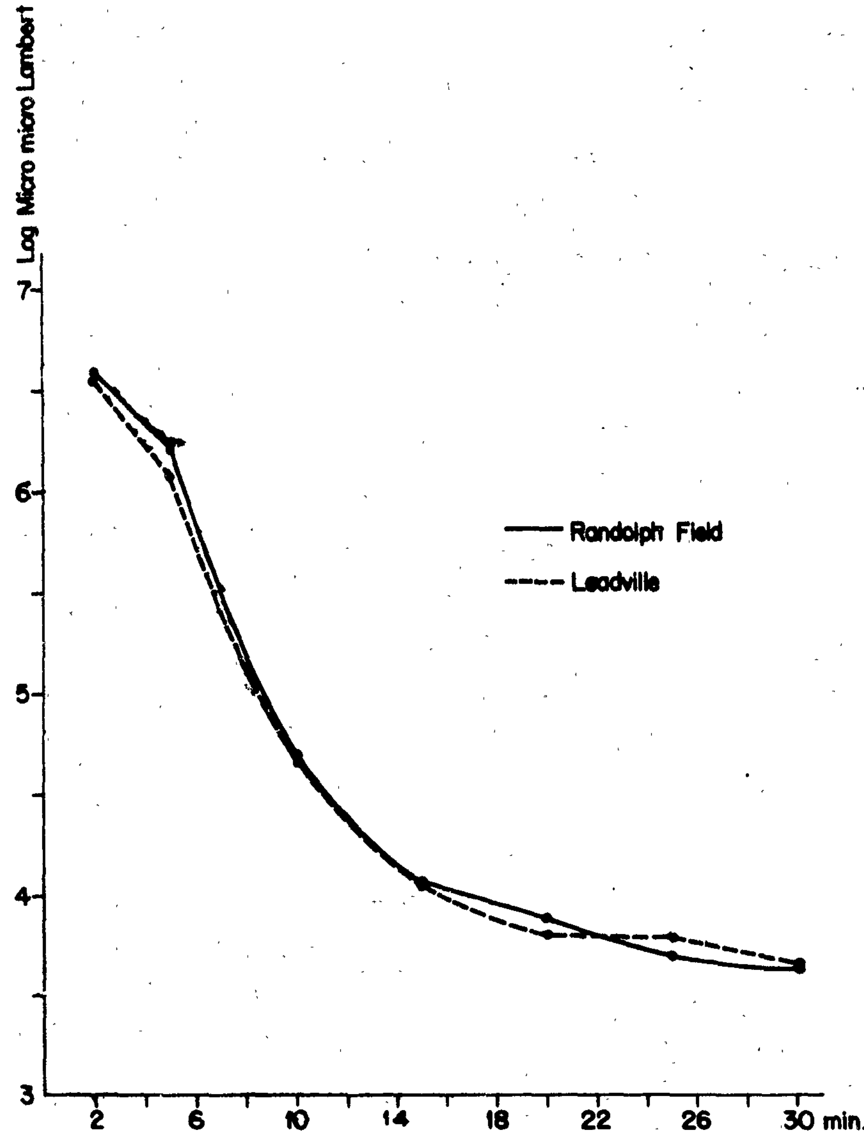

FIGURE 6

Mean values of night vision thresholds of 12 subjects. The values of two tests of each subject at Randolph Field (RC_1 and RC_2 are consolidated into one curve and the values of 5 tests at Leadville (L_1, L_2, L_3, L_4, and L_5) into another curve.

deteriorations of the visual acuity or a prolongation of the periods required for obtaining certain visual acuities[5,6,7]. Hence, the eye is here in the range of incomplete compensation. On the other hand, it is noted in figure 1 that there is no deterioration when comparing visual acuity at Randolph Field with that at Leadville (RC_1 and RC_2 as compared to L_1). The statistical evaluation of $\frac{RC_1 \text{ and } RC_2}{2}$ vs. L_1 yields for all evaluated measurements with the nyktometer a P(I) which is greater than 0.30. The conclusion can therefore be made that there would be no difference between the control values RC_1 and RC_2 compared with L_1. Hence, during the measurements L_1, with regard to the oxygen deficiency

TABLE 5
Mean Values of Heterophoria Tests on 10 Subjects
and of Fusion Tests on 9 Subjects

	Days of Tests								
	RC_1	L_1	L_2	L_3	L_4	L_5	Rl_1	R	Rl_2
Prism Diopters									
Phoria	-0.5	0.2	-1.0	-1.6	-2.3	-1.7	-1.1	-1.6	-0.6
Power of Adduction	13.2	17.2	22.4	21.3	22.6	21.8	20.5	19.1	16.7
Power of Abduction	5.9	8.9	7.9	6.5	6.4	6.9	7.8	5.9	6.4

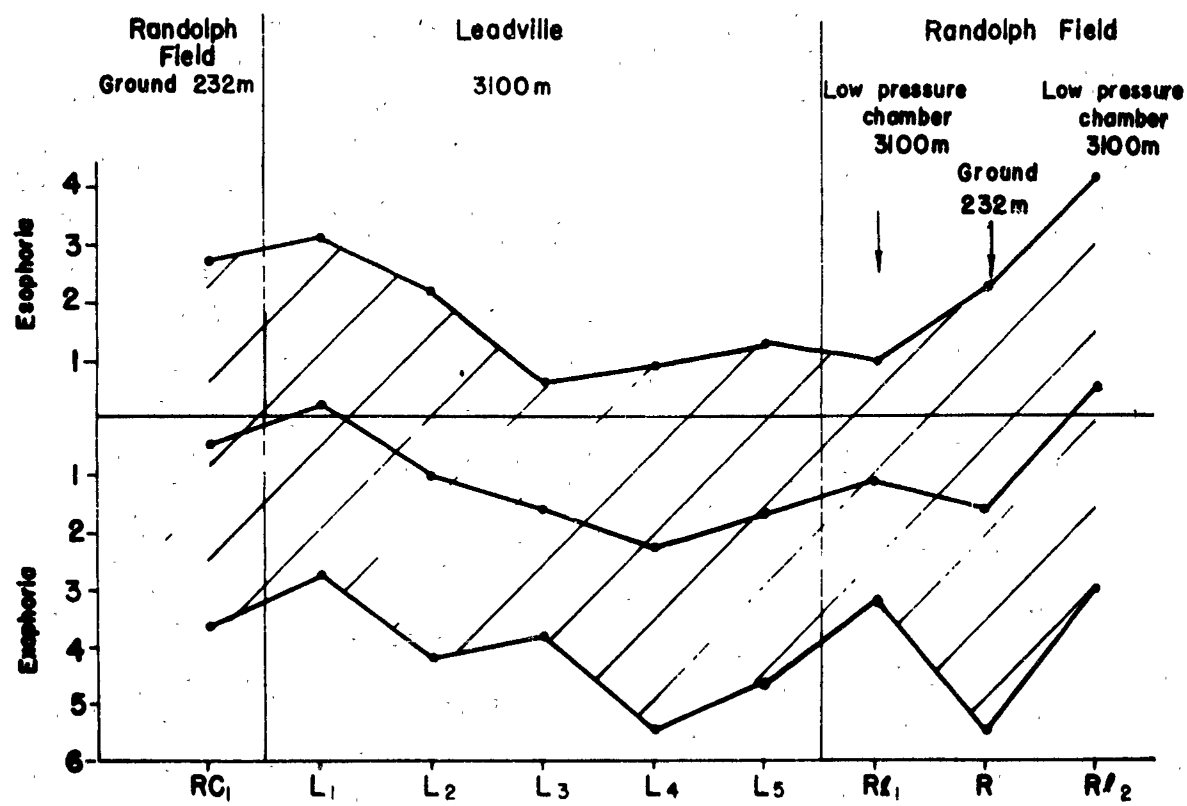

FIGURE 7
Phoria. Middle: Mean values of two tests with 10 subjects. Upper and lower curve: Borderline of the range of error according to S. Koller. Ordinate in prism diopters.

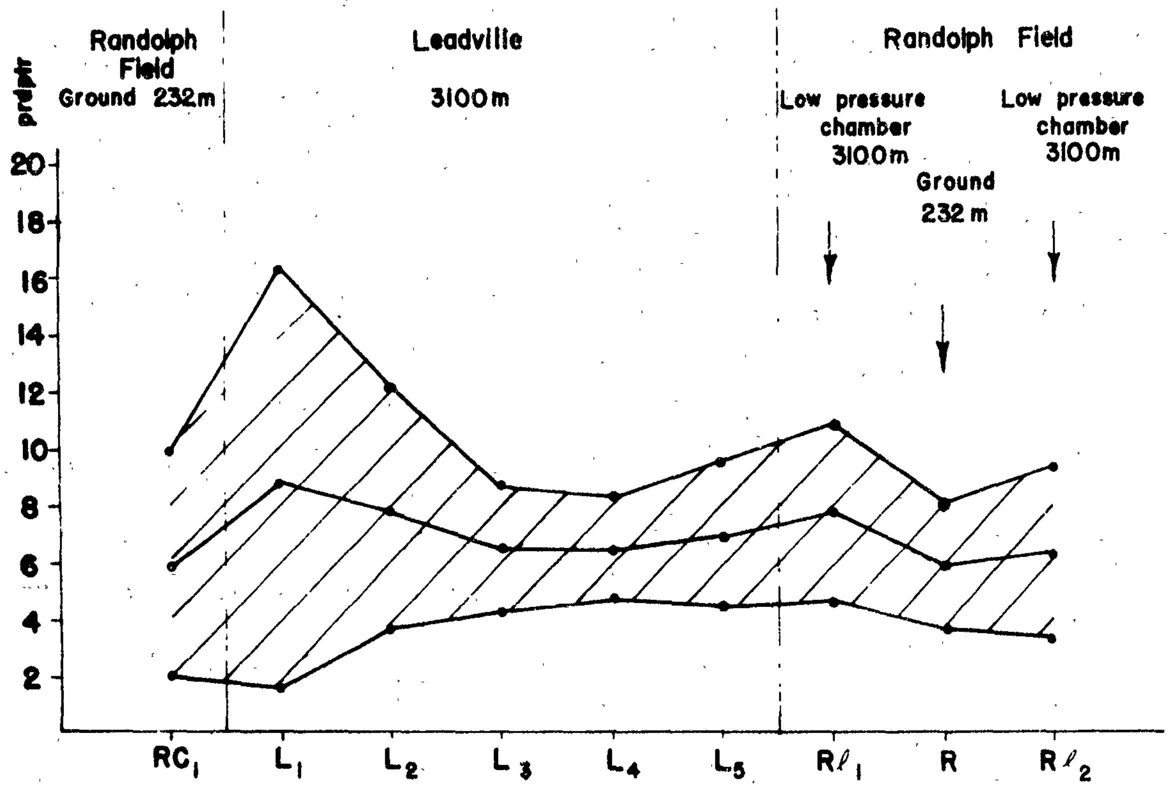

FIGURE 8
Power of Abduction. Middle curve: Mean values of two tests with 9 subjects. Upper and lower curve: Borderline of the range of error according to S. Koller. Ordinate in prism diopters.

of the respiratory air, complete compensation must have been established in the retina and cerebral portion of the visual tract. At present, the mechanism of this complete compensation can only by presumed. Respiratory volume and cardiac minute volume yield no explanation for this phenomenon. The regeneration of hemoglobin does not occur this rapidly. It may be possible that the dilatation of the retinal and cerebral vessels produces this effect. The measurements mentioned were made 26 to 31 hours after leaving Randolph Field. The 5-hour flight to Colorado Springs was carried out at an altitude of about 2,000 m. (6,600 ft.). Colorado Springs has an altitude of 1,800 m. (5,900 ft.), but about two hours after leaving Colorado Springs altitudes of 2,400 m. (7773 ft.) were attained at Cascade. During most of the 4½ hour ride to Leadville, the altitudes varied between 2,400 and 2,800 m. (7,869 and 9180 ft.), however, near Leadville 3,000 m. (10,000 ft.) was exceeded. Hence, it can be said that prior to measurements at high altitude, the test subjects had passed 24 to 29 hours above 2,000 m. (6,600 ft.). But 2,000 m. is just sufficient to initiate the respiratory and circulatory regulative processes. Since the speed of ascent is a very decisive factor for the onset of failure due to oxygen lack, it may be possible that an initial deterioration of twilight vision did not occur because of the slow ascent. If there were an initial deterioration, no well founded statement about its beginning could be made for lack of measurements during that 24 hour period. The further course of the tracings in figure 1 shows no essential changes during the stay at high altitudes. Also the statistical evaluation, giving values for P (I) of greater than 0.30, suggests that during

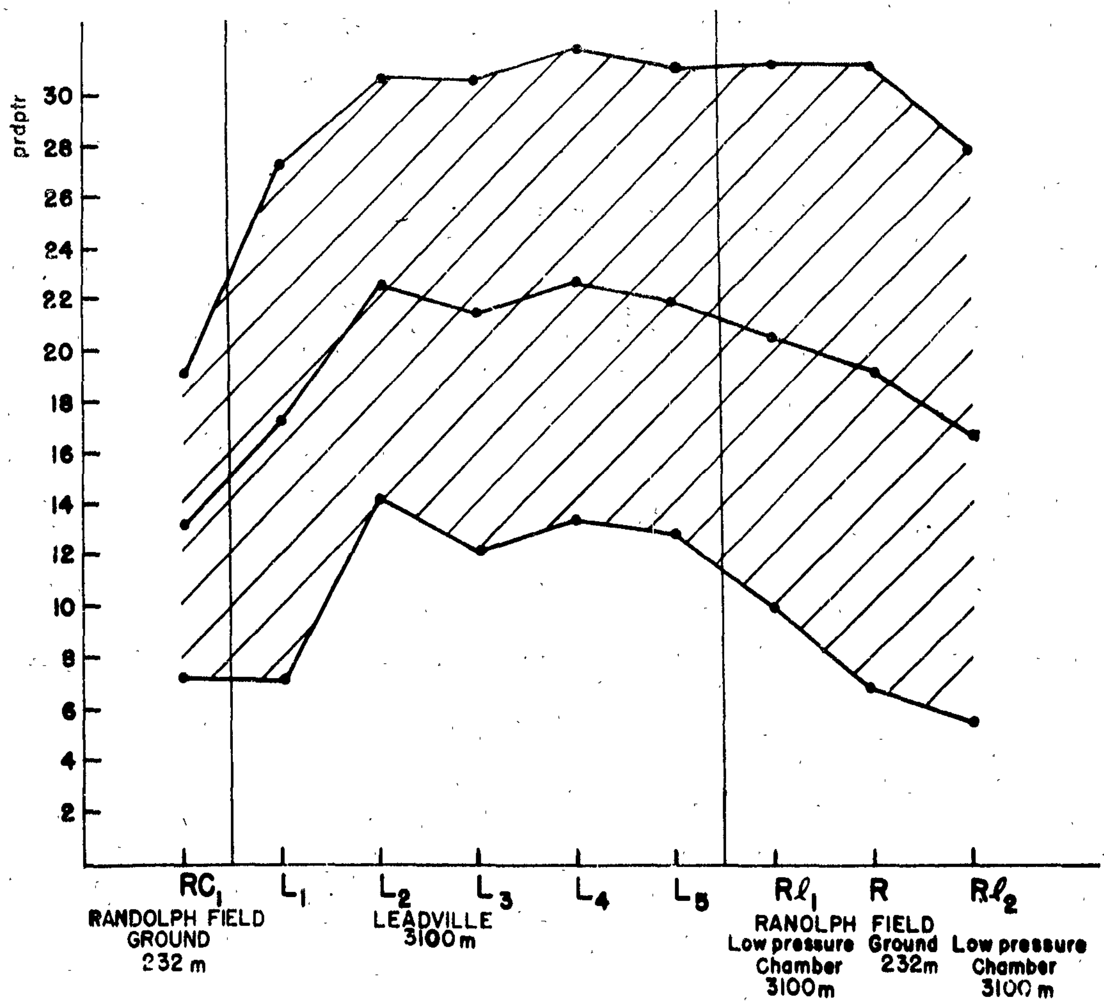

FIGURE 9

Power of adduction. Middle curve: Mean values of two tests with 9 subjects. Upper and lower curves: Borderline of range of error according to S. Koller. Ordinate in prism diopters.

the stay at high altitude the twilight vision had not changed. However, this does not exclude the possibility that a stay at high altitude which varied in length of time might not have an aftereffect which likewise would vary in length of time. In this case---analogous to the facts of genetics, that equal genotype does not necessarily correspond to equal phaenotype---the lack of change of the function of twilight visual acuity during stay at high altitude does not mean that the fundamental physicochemical processes have not changed.

The deterioration of the visual acuity $\frac{L_4 + L_5}{2}$ as compared to Rl_1 as shown in the *120 sec.* curve is unexpected; but statistically, this difference is significant. P (I) amounts to only 0.0027 and is thus significant even for critical requirements. At the same time the three upper curves indicate a deterioration. These deteriorations are not large enough to be significant at a level as low as P(I) = 0.0027. They are, however, significant at a level of P(I) = 0.01, which many researchers are willing to accept. The aftereffect of the high altitude acclimatization of

TABLE 6
Statistical Evaluation of the Heterophoria and Fusion Tests

		Compared Tests			
		RC_1 vs. L_1	L_1 vs. $\frac{L_4 + L_5}{2}$	$\frac{L_4 + L_5}{2}$ vs. Rl_1	R vs. Rl_2
Phoria	Observed Difference	0.3	2.2	0.9	2.2
	P(I)	> 0.30	0.027	> 0.30	0.058
	$P(II_{0.05})$	4.1	3.6		4.1
	$P(II_{0.01})$	5.0	4.3		5.0
	$P(II_{0.0027})$	5.1	4.4		5.1
Power of Adduction	Observed Difference	4.0	5.0	1.5	1.4
	P(I)	0.12	0.034	> 0.30	> 0.30
	$P(II_{0.05})$	10.0	8.7		10.0
	$P(II_{0.01})$	12.0	10.4		12.0
	$P(II_{0.0027})$	12.1	10.5		12.1
Power of Abduction	Observed Difference	7.4	2.2	1.1	0.5
	P(I)	0.031	0.059	> 0.30	> 0.30
	$P(II_{0.05})$	5.1	4.4		5.1
	$P(II_{0.01})$	6.1	5.3		6.1
	$P(II_{0.0027})$	6.2	5.4		6.2

*For the meaning of P(II) see footnotes to table 2.

twilight visual acuity fades relatively fast, *i.e.*, after ten days. If we accept this assumption as correct, then the two experiments R and Rl_2 must be considered as ordinary control and decompression chamber tests without high altitude acclimatization effects. The changes occur here as expected. Failure of a change for the *120 sec.* curve and the relatively low statistical reliability of the changes in the three upper curves may be easily explained by the small number of test subjects. The measurements of the night visual threshold are not easily explained. Numerous researchers of various countries agree that the night visual threshold is higher when under oxygen deficiency in the decompression chamber.

A curve, obtained by the apparatus employed, can be found in the report listed in the bibliography under 6. In observing the seven curves of figure 2, 3, and 4 it is astonishing that at the point of transition from Randolph Field (RC_1 and RC_2) to high altitude (L_1) the night visual threshold value decreases; an improvement occurs. The improvement was slight and the differences between the individual curves were statistically not verified, but the improvement is evident in all seven curves of the mean values. Also the measurements of L_1 were still inside the range of normal thresholds. The possibility of an improvement in night vision above normal values, which has often been discussed in recent years, could not be confirmed. All curves of the mean values show in their patterns (from test L_1 to test L_5) a slight increase in the threshold values; a deterioration. Statistically, this deterioration could be verified to only a slight extent. The values of P (I) are between 0.01 and 0.02 for five points of the curves. Many researchers, however, consider such values of a P (I) as adequate, but P (I) of smaller than 0.0027 is more desirable for biological investigations. Were this threshold increase real, its explanation would be quite difficult and hypothetical. The coincidence of the two curves of figure 6 suggests that the night visual threshold has not changed. When computing these mean values, it is, however, not considered that individuals sho·· very diverse reactions, as can be seen in figu : 5. The values of the thresholds in the decompression chamber, evident ten days after completion of the high altitude sojourn, are still in harmony with the last high altitude values L_4 and L_5. In this case, the aftereffect of the high altitude acclimatization would continue for ten days. The differences between R and Rl_2 correspond to the deteriorations of the threshold anticipated in the decompression chamber under the assumption that the high altitude acclimatization has been lost.

Insofar as problems of heterophoria and fusion in case of oxygen deficiency are concerned, we have a series of publications. The majority are based on short-time decompression chamber tests. Mentioned here are a few examples[8, 9, 10, 11, 12]. McFarland[13] conducted examinations before and after a 24 hour trip by railroad from sea level to an altitude of 4,450 m. (14,590 ft.). The authors cited found changes at high altitude. They could not agree, however, on the direction of the changes. Some found an increase in the heterophoria present, others found changes in the sense of decreasing exophoria and increasing esophoria. It may be possible that some findings of this work can reconcile the contradicting concepts of other authors.

In the tests described here the direction of the changes depend on the length of stay at high altitude. Figure 7 shows changes toward esophoria in the transition from RC_1 to L_1, which is in conformity with the findings of Velhagen[11]. During the stay at high altitude this change is replaced by a counteraction exceeding the value RC_1. Rl_1 approaches these values quite closely during : e high altitude acclimatization. It shows that the high altitude acclimatization prevails for at least ten days. The values R and Rl_2 for heterophoria change toward esophoria as described by Velhagen for the short time decompression chamber test. Hence, the high altitude acclimatization had faded by the time the tests R and Rl_2 were carried out. On account of the small number of test subjects only the difference between L_1 and $\frac{L_4 + L_5}{2}$ is for very modest requirements statistically established by P (I) = 0.027. The other three statistically evaluated differences in heterophoria in table 6 are too small to be considered significant. The ranges of error indicated according to the method of Koller, clearly explain this.

The investigation of the power of abduction shows a course which, with regard to direction and extent, is similar to that of heterophoria. In this case only the difference between RC_1 and L_1 with a P(I) of 0.037 is great enough to satisfy modest requirements for significance. The values of the required minimum differences of the true means stated for P (II) = 0.05 are, however, so great that the assumption of a real difference seems justified. The investigations of the power of adduction (figure 9) are usually subjected to greater sources of error. The range of error, according to Koller, is here essentially higher than in figure 8, despite the same number of test subjects. Also in this case we notice a two-phase course. There is an increase from RC_1 to L_1 and L_2. These values are maintained during the stay at high altitude. Only the difference between L_1 and $\frac{L_4 + L_5}{2}$ is of adequate significance for modest requirements. The drop of the power of adduction from R to Rl_2 is remarkable. Because of the limited accuracy of this examination of the adduction power, definite conclusions are not drawn. Changes of heterophoria and adduction forces must be conceived rather as tonus-fluctuations in the autonomic nervous system with compensation and hyper-compensation effects. The second phase of the changes during the high altitude sojourn, running counter to the first, coincides here somewhat with the decline of the increased activity of respiration and heart and with the increase in hemoglobin. It remains doubtful whether any relationship exists here. It seems very doubtful that slight disturbances in the ocular muscles have any significance for the flier. The ocular muscles are here mainly as indicators of tonus changes in the autonomic nervous system, but twilight and night vision changes have a direct specific value for the flier. The tests described reveal changes during the first and second part of the high altitude acclimatization, which are partly the reverse of those of the short-time decompression chamber test. It is possible that these regulation processes begin within a span of time which corresponds to the duration of flight of present long distance aircraft. The slight oxygen deficiency as it exists in pressure cabin aircraft might be sufficient to initiate these regulatory processes. A further investigation of these circumstances seems promising. The problem of oxygen deficiency cannot be considered as solved so long, and as far as, the pressure cabin is intact. It is inadequate to concentrate attention only on defects of the pressure cabin. Even in the era of the pressure cabin the high altitude acclimatisation of fliers may still be of interest.

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