THE ATHLETIC PERFORMANCE

AT SEA LEVEL OF

MIDDLE ALTITUDE DWELLING GIRLS

by

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ABSTRACT

With the consideration of extending track competition for girls of a middle altitude community to include the sea level valley nearby, the problem for this investigation evolved. The main question to be answered was, "Is the athletic performance of young female athletes, native to middle altitude, impaired when performing at sea level?" Subsidiary problems of the relationship of partial pressure of oxygen to performance, and microhematocrit changes in the subjects were also studied.

Eight females between the ages of 12 and 14 participated in this experiment having eight treatments. Four treatments were at sea level and four were at middle altitude. Each treatment included taking a fingertip blood sample for a microhematocrit reading, a 50 yard dash, a 440 yard dash, a softball throw and an 880 yard run. These events were to represent the assortment found at a track meet. Recordings were also made of temperature, humidity, barometric pressure, and air pollution.

It was hypothesized that; a) the denser air and increased gravitational pull at sea level cause impairment in throwing and short runs; b) with oxygen uptake reduced at altitude, the 880 yard run is faster at sea level than at middle altitude; c) if hematocrits are in the upper portion of the normal range for sea level, the resultant increase in the oxygen carrying capacity of the blood does not improve sea level performance.

The findings indicated that physical training and learning progressed markedly from the start of the experiment to the

finish. The only significant altitude effect was found in the 50 yard dash with times being faster at sea level. It is doubtful that this was a result of the change in altitude, more likely, conditions other than barometric pressure were responsible for the differences found at the two testing locations. Wind disadvantage and insufficient warm-up more likely accounted for slower times at altitude. Superior performances occurred in warm weather, and when subjects were psychologically peaked indicating that warm-up and psychological climate may be more important to performance than the change of altitude that was employed. Hematocrits remained within normal ranges for middle altitude dwelling females throughout the experiment.

Therefore, a coach of healthy young athletes from middle altitude should have no unusual concerns for competition at a related sea level environment. Concerns should be only those normally attended to at all competitions.

PREFACE

For a number of years coaches in a mountain community in California have spent time discussing the headaches, dizziness, nausea, and exhaustion experienced by their athletes during competitions at sea level. Were these symptoms the result of hyperventilation and unaccustomed temperatures occurring at sea level? Or, were they mainly due to inadequate training which was partly the result of a short season of good weather at altitude?

In 1968 United States track, volleyball, and gymnastic teams trained in this community prior to the Olympics in Mexico City. Little of significance was learned from these training camps to help the local coaches. Since, recent trends have been to include more school competition for girls as well as boys, and pressures have been exerted to extend the geographical area included in competition schedules, there was cause to embark on the following experiment.

Special thanks is due Dr. Kenneth Smith, a long time resident of Lake Tahoe--a Medical Doctor and researcher on middle altitude. He provided all the facilities and equipment necessary for doing the microhematocrits, and his automobile provided the major share of transportation. As the ultimate token of Dr. Smith's faith he loaned his daughter as a subject. The Jeffries family is also thanked for helping with transportation, providing a subject and making a swimming pool available after testing sessions. My parents were a great help to provide lunch, a rest stop and assistance when needed. Finally, the

College of Marin and its Athletic Director Harry Pieper have all my gratitude for allowing the use of their impressive grounds and facilities for the sea level testing.

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THE PROBLEM

Between the 1955 Pan American Games and the 1958 Olympics in Mexico City the study of altitude acclimatization accelerated. It was important to know the effects of 7,200 feet elevation upon athletes so that better training procedures could be planned. Little attention, however, was given specifically to the adaptation of females or to the problems of athletes living at middle altitude who frequently compete at sea level.

The purpose of this investigation is to determine if the performance of young female athletes, native to middle altitude, is impaired when performing at sea level without benefit of deacclimatization, and possible reasons for any decrement in performance.

Problem:

What are the differences in performance of selected track events at the two levels of altitude?

Subproblems:

a. What is the relationship of the two levels of barometric pressure to performance?

b. How does hematocrit differ in the subjects from sea level norms?

Definitions

Middle altitude - generally refers to altitudes between 5,000 and 7,000 feet. Specifically in this study the elevation at which the subjects live is approximately 6,256 feet.

Deacclimatization - the process of losing physiological responses which adapt one to altitude conditions and the process of acquiring responses appropriate to sea level conditions.

PIO_2 - partial pressure of inspired oxygen. The atmosphere's pressure and density are highest at the surface of the earth and decrease exponentially with altitude. With a constant oxygen concentration of 20.94% of the dry air, the oxygen pressure of the inspired air in trachea, saturated with water vapor, can be calculated from the formula PIO_2 = (p bar - 47) 20.94/100.

Hematocrit - percent of the cells and other particulate elements of the blood. In this investigation a microhematocrit technique was used.

Performance - operationally defined as the times or distances achieved by the athletes when tested.

Delimitations

The universe is limited to girls 12-14 years of age who live at middle altitude. The sample of eight subjects is fairly small in order to keep testing and transportation within practical limits.

Assumptions and Limitations

A serious limitation was the inability to manipulate the environmental factors of temperature and humidity.

Hypotheses

a. The denser air and increased gravitational pull at sea level cause impairment in throwing and short runs.

b. With maximal oxygen uptake reduced at altitude, the 880 yard run is faster at sea level than at middle altitude.

c. If hematocrits are in the upper portion of the normal range for sea level, the resultant increase in the oxygen carrying capacity of the blood does not improve sea level performance.

Significance of the Study

In practical terms, this study may have significance for coaches at middle altitude in deciding whether to include contests at sea level in the competition schedule.

The process of high-altitude deacclimatization has been investigated less than the acclimatization process, yet the studies that have been conducted indicate deacclimatization represents a major transient taking some time to complete. Reynafarje (1958),[1] Dejours, Kellogg, and Pace (1963),[2] Daniels and Oldridge (1970),[3] all reported physiological adjustments of deacclimatization taking from 30 to 120 days to complete.

A personal communication from Dr. Nello Pace related, too, that acclimatized individuals who return to sea level may experience a characteristic subjective feeling of lassitude for

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[1]C. Reynafarje, "The Polycythemia of High Altitudes: Iron Metabolism and Related Aspects," Blood, 14, 1959, 433-455.

[2]Pierre Dejours, Ralph Kellogg, and Nello Pace, "Regulation of Respiration and Heart Rate Response in Exercise during Altitude Acclimatization," J. Appl. Physiol. 18 (I):1963, 10-18.

[3]Jack Daniels and Neil Oldridge, "The Effects of Alternate Exposure to Altitude and Sea Level on World-class Middle-distance Runners," Medicine and Science in Sports, Vol. 2, no. 3, (Fall 1970), 107-112.

a day or two.[4]

As far as impairment of athletic performance under these circumstances, statistical data seem to be lacking. Effects on athletic performance differ depending on how long athletes were at altitude, the altitude at which they stayed, the type of training they were involved in, the state of training before the experiment and other conditions of the experiment.

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[4]Nello Pace, a copy of the referred to communication appears in the appendix.

Chapter 2

REVIEW OF THE LITERATURE

The stimuli for investigating man's adaption to altitude have come from a variety of sources. The wartime need to fly at high altitude, the mountaineers' need to survive on high peaks, and the athletes' need to perform competitively at moderate altitudes have all prompted research to extend what is known about men living and working at altitude.

There is little information regarding the specifics of female adaption. Indications are that women may respond somewhat differently from men. Physiological studies at middle altitude are scarce and despite the quantities of high altitude work, factors contributing to limiting performance at altitude need better definition.[1] The main adjustments apparent in man during exposure to altitude are the result of the response to diminished oxygen tension. However, the effects of a change of environmental temperature and humidity, which are not unique to high altitude, are also of great importance. Tenney (1968) claims the evidence of effects specific to a reduced barometric pressure is not convincing.[2]

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[1] Albert B. Craig, "Olympics 1968: A Post Mortem," Medicine and Science in Sport, Vol. 1, no. 4, (December 1969), 177-180.

[2] S. M. Tenney, "Physiological Adaptations to Life at High Altitude," in E. Jokl (ed.) Medicine and Sport, Exercise and Altitude, (Basel, S. Karger, 1968), 60-70.

Furthermore there is really no threshold altitude for the so-called "high altitude effects". Altitude acclimatization is a continuous process from sea level to the civilizations resident at very high altitudes, (Tenney, 1968)[3] hence, studies cited of high altitude work may be expected to be exaggerations of the effects of middle altitude.

Athletic Performance at Altitude and Sea Level

At a symposium in 1966 Balke expressed his theory that training at moderate altitude should be used for improving performance at sea level.[4] Such a statement was the result of his study into the effects of altitude upon athletic performance. Balke (1964) trained five men at 2400 meters for ten days and concluded that physical performances greatly dependent upon maximum aerobic capacity were initially reduced at altitude. Extensive training possibly aided by training at even higher elevations seemed to restore "normal" capacity for aerobic work. Further tests were conducted at sea level and then again at altitude. The second altitude tests produced clockings better than the previous best altitude performances.[5] The occurrence of increasingly better performances with alternate exposure to altitude and sea level provoked further thought and research by Balke, his

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[3]Tenney, loc. cit.

[4]Bruno Balke, "Summary of Magglingen Symposium on Sports at Medium Altitude," in R. F. Goddard (ed.) The International Symposium on the Effects of Altitude on Physical Performance, (The Athletic Institute, Chicago, 1966), 106-107.

[5]Bruno Balke, J. Faulkner, J. Daniels, "Maximum Performance Capacity at Sea-level and at Moderate Altitude Before and After Training at Altitude," Schweizerische Zeitschrift fur Sportmedizin, Vol. 14, 1965, 106-117.

colleagues, and others.

Along these same lines of thinking, W. A. Bynum (1966) hypothesized that natives of high altitude would show an increase in work capacity upon descending to a lower altitude. Bynum's experiment was well controlled using a chamber and tests requiring maximum oxygen uptake. Conclusions were that upon descending to sea level after altitude acclimatization to an elevation of 5,170 feet, a highly conditioned athlete would probably experience the following results:

1. A reduction in resting pulse rate.
2. No change in resting ventilation rate.
3. No change in terminal pulse rate following an all-out treadmill run.
4. He would be able to increase his treadmill run time (or work capacity) without increasing his recovery pulse rate.
5. He would be able to perform at a higher cardiorespiratory work level than he was capable of at altitude.[6]

This study, too, makes living and training at middle altitude appear advantageous for athletes competing at sea level. However, since environmental conditions were controlled and the performance was of maximum capacity, such conclusions apply only to endurance events held under tolerable conditions.

Grover and Reeves (1966) wondered if life long acclimatization to the chronic hypoxia of altitude would give the native an advantage over the newcomer in terms of exercise performance

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[6] W. A. Bynum, "Work Capacity of Altitude Acclimatized Men at Altitude and Sea Level," in R. F. Goddard (ed.) _The International Symposium on the Effects of Altitude on Physical Performance_, (The Athletic Institute, Chicago, 1966).

at medium altitude. In addition, would adaptation to medium altitude modify physical working capacity at low altitude? The five low altitude athletes, on an average, had a 25% decrease in maximum oxygen uptake on the first day of arrival at altitude. On further stay, this did not improve, due to the high level of fitness possessed on arrival. There was no evidence that the sojourn at medium altitude improved performance later at sea level. In fact, four of the five men had a lower maximum oxygen uptake than originally. The effect of altitude change for the middle altitude residents was virtually the same. The athletes from middle altitude displayed persistent hyperventilation at sea level, they also had a higher pulmonary diffusion capacity which would theoretically give them an advantage at 3,100 meters. Although both groups had almost identical physical working capacity, the performance measurements in this study are difficult to interpret since the sea level group had superior skill and competition was not on a par.[7]

Balke et al. (1965) made a pertinent comment regarding some similar high altitude studies. "For proper high performance athletic training one needs adequate facilities--tracks and heated swimming pools. Without them, the essential coordination for proper pace and rhythm will suffer."[8] So it would seem the physiological advantages of altitude acclimatization do not alone produce superior performances if the facilities

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[7]Robert Grover, John Reeves, "Exercise Performance of Athletes at Sea Level and 3,000 meters Altitude," The International Symposium on the Effects of Altitude on Physical Performance (The Athletic Institute, Chicago, 1966), 80.

[8]Bruno Balke (1965), loc. cit.

and coaching have been inadequate. Another difference in the studies made by Balke et al. (1965) and Grover and Reeves (1965) was that the subjects in the first study were not well trained at the beginning. This, too, may account for differences in the results.

Daniels and Oldridge (1970) studied effects of alternate exposure to altitude and sea level on world-class middle-distance runners. The most obvious difference found was a higher maximum oxygen uptake on all post altitude tests compared with pre-altitude or altitude values. Improvement in ventilatory capacity was noted after altitude training, but it was not clear whether this improvement was of benefit upon return to sea level. On descending to sea level, Daniels and Oldridge (1970) reported that the hypersensitivity of the respiratory center recedes slowly. During the transient period the athlete breathed more air for any given work intensity than he did at sea level prior to altitude exposure. The additional work involved in moving this greater volume requires more oxygen which is provided at the expense of the oxygen demands of the muscles used in running. The result could be a) a performance decrease in the absence of an increase in maximum oxygen uptake; b) a performance equal to that previously attained at sea level; c) a better sea level performance if an increase in maximum oxygen uptake could over compensate for the greater ventilatory demands.[9]

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[9] Jack Daniels, Neil Oldridge, loc. cit.

Buskirk et al. (1966) as well as Consolazio (1966) stated that their subjects who stayed at altitudes up to about 4,000 meters for four weeks or more did not attain any better results than usual when they returned to sea level. The measured maximum oxygen uptake was not improved.[10,11] Buskirk, et al. concluded that there is little evidence to indicate that performance on return from altitude is better than before going to high altitude.[12] Their results support the concept that once a person is well trained it is difficult to achieve further significant training effects.

As for what actually has occurred in athletic competitions at various altitudes, Ernst and Peter Jokl (1968) examined world records, Olympic records, and Pan American swimming times. The summarized effect of reduced oxygen tension at altitudes between 5,000 and 7,000 feet upon athletic performance was that contests of between 100 and 400 meters produced slightly better results than at sea level, while running times in middle and long distance races were slower. They figured the handicapping influence of the lowered oxygen pressures becomes statistically valid at 5,350 feet only for distances of 1,500 meters and longer. The Jokls concluded that even though training at altitude for high altitude competition is useful, it does not nullify

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[10]E. Buskirk et al. "Physiology and Performance of Track Athletes at Various Altitudes in the United States and Peru," in R. F. Goddard (ed.) The International Symposium on the Effects of Altitude on Physical Performance, 1966.

[11]C. F. Consolazio, "Submaximal and Maximal Performance at High Altitude," ibid., p. 91.

[12]E. Buskirk et al., op. cit.

the inhibiting effect of altitude upon endurance.[13] Craig (1969) analyzed the 1968 Olympics and also found winning times in the longer events proportionately slower than world records. But, there were several outstanding efforts which were far better than predicted possible at the altitude of Mexico City.[14]

Ventilatory Response

Acclimatization to high altitude begins with hyperventilation in response to hypoxia. This first phase ends several days after arrival upon completion of renal compensation for the resultant respiratory alkalosis. To Hornbein and Roos (1962) it appeared that the chemoreceptors activity as modified by sympathetic control of blood supply to the carotid and aortic bodies may be an important determinant of the ventilatory response to exercise. The ventilatory response to exercise is enhanced by very mild hypoxia. This is sufficient to initiate the acclimatization to altitudes so low that resting ventilation on acute exposure is not affected.[15]

Tenney (1968) summarized the ventilatory response by calling the lower arterial oxygen tension of high altitude a more potent stimulus. As a consequence, chemoreceptor output increases, ventilation increases, and this response serves to minimize the partial pressure drop from the inspired air to the

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[13]Ernst and Peter Jokl, "The Effect of Altitude on Athletic Performance," in E. Jokl (ed.) Medicine and Sport, Exercise and Altitude, (Basel, S. Karger, 1968), p. 28.

[14]Craig, op. cit., p. 178.

[15]Thomas Hornbein and Albert Roos, "Effect of Mild Hypoxia on Ventilation During Exercise," J. Appl. Physiol., 17 (2) 1962, p. 239.

alveolar air. During the early period of high altitude adaptation, there is an extremely important change in this mechanism. The hypoxia-evoked ventilatory response brings about a fall of alveolar carbon dioxide pressure, and this resultant hypocapnia exerts an inhibitory influence on the respiratory centers. So, the final effect in acclimatization is a comparatively small increase in ventilation. The renal response to the uncompensated respiratory alkalosis results in the conservation of hydrogen ions and the excretion of fixed base in the urine to restore the pH of the blood to normal. This is largely accomplished during the first week of high altitude residence, and during this time there is a gradual shift in the sensitivity of the respiratory centers to carbon dioxide in such a way that once again dominant, but not exclusive respiratory control is exerted by carbon dioxide.[16]

As previously mentioned, the hypersensitivity of the respiratory center recedes slowly on descent to sea level. Kellogg has shown that the return of the normal CO_2 sensitivity of the respiratory center requires about 30 days to be completed.[17] Perhaps because of this relatively slow deacclimatization process Dejours, Kellogg, and Pace (1963) found that if an altitude acclimatized individual were suddenly restored to a normal oxygen supply, respiration was immediately reduced, but

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[16] S. M. Tenney, "Physiological Adaptations to Life at High Altitude," in E. Jokl (ed.), Medicine and Sport, Exercise and Altitude, 1968, p. 66.

[17] Op. cit. Based on personal correspondence between Dr. Nello Pace, Physiology Department, University of California, and the writer.

not to the pre-altitude level.[18] Daniels and Oldridge (1970) had similar findings from alternate tests at sea level and altitude. On acute exposure to altitude MVV and max VE (BTPS) increased proportionately; however, max VE eventually increased slightly more than did MVV. Subsequent sea level values for max VE were also higher than those reached in initial sea level tests.[19]

Max VO_2 values initially dropped 14% upon acute exposure to altitude. By the third week at altitude this was improved to a 10% decrement. It remained relatively unchanged until another slight improvement to within 8% of the original sea level values by the subjects who were at altitude for six weeks. Max VO_2 during the first intermittent and final sea level exposures was slightly higher than the pre-altitude value. They found an obviously higher VO_2 at all running speeds during post altitude tests compared with either pre-altitude or altitude values.[20]

The ability of the high altitude acclimatized individual to transport oxygen to the cellular level may be enhanced by an increase in alveolar capillary diffusing area. In any case the pulmonary diffusing capacity for oxygen is increased. Tenney (1968) discussed the various pressure gradients and in adapting to the reduced oxygen pressure found at altitude there must be

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[18] Pierre Dejours, Ralph Kellogg, and Nello Pace, "Regulation of Respiration and Heart Rate Response in Exercise During Altitude Acclimatization," J. Appl. Physiol., 18 (1), 1963, pp. 10-18.

[19] Jack Daniels and Neil Oldridge, "The Effects of Alternate Exposure to Altitude and Sea Level on World-class Middle-distance Runners," Medicine and Science in Sports, Vol. 2, no. 3, (Fall 1970), 107-112.

[20] Ibid.

a compensatory adjustment in a more distal gradient in order to preserve the cellular value needed. The ventilatory changes associated with altitude acclimatization stabilize within the first few days at altitude.[21] Circulatory adjustments to exercise change comparatively slowly. Other changes such as acid-base adjustments, erythropoietic adjustments, endocrine response, and peripheral tissue changes are far from complete within the first few days.

Changes in the Blood

Within hours of arrival at altitude there are changes in the blood and its oxygen carrying capacity. Firstly, the numbers of erythrocytes increases, hemoglobin synthesis may be depressed at this time. Hematocrit also increases with relation to figures obtained at sea level, hence showing a tendency toward microcytosis during the first few days of arrival at altitude. Increase in erythrocytes and hemoglobin is progressive, requiring ten to fifteen days to acquire values comparable or very close to the ones encountered in those native to high altitude (Merino, 1950).[22]

Merino (1950) as well as Reynafarje (1959) found in natives of high altitude who have descended to sea level a marked acceleration of blood destruction occurring during the first hours of descent. (However, this investigator noted on their graphs an increase in red blood cells on the first test

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[21] S. M. Tenney, loc. cit.

[22] C. Merino, "Studies on Blood Formation and Destruction in the Polycythemia of High Altitudes," Blood, 5, 1950, 1-32.

taken immediately on arrival at sea level. A decrease followed the first testing. No explanation or comment was available for this initial recording.) The decrease in hemoglobin and red blood cells reaches its maximum between the seventeenth and thirty-fifth days, and this is followed by a gradual increase of the red blood cell and Fe turnover rate until it reaches about the normal rate. This occurs 100 to 120 days after the environmental change (Reynafarje, 1959).[23]

Schmidt and Gilbertsen (1955) refute the thought that bone marrow anoxia is directly responsible for increased erythropoiesis in chronic anoxemia. An autopsy of a woman with an arterial shunt affecting only the lower extremities directed their suggestion that anoxemia of the blood stimulates the production or release of a humoral factor which in turn acts as an erythropoietic stimulus.[24]

Hornbein (1962) stated that a normal adult male is thought to possess 800-1,500 mg. of iron in storage depots available for hemoglobin synthesis. Hornbein surmised that the sum of pre-existent stores and the currently absorbed iron would roughly parallel the amount required to achieve the polycythemic response observed in his subjects.[25]

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[23] C. Reynafarje, "The Polycythemia of High Altitudes: Iron Metabolism and Related Aspects," Blood, 14, 1959, 433-455.

[24] R. Schmidt, and A. S. Gilbertsen, "Fundamental Observations on the Production of Compensatory Polycythemia," Blood, 10, 1955, 247-251.

[25] Thomas F. Hornbein, "Evaluation of Iron Stores as Limiting High Altitude Polycythemia," J. Appl. Physiol., 17 (2), 1962, p. 244.

Hannon, Shields, and Harris (1966) on the other hand found that their women subjects did not show the increase in hematocrit expected during acclimatization unless they received iron supplement. Despite the lower hematocrits, these women subjects adapted to altitude rapidly. Indications were that other adjustments played their part in providing oxygen at the cellular level.[26]

Cardiac Response

Grollman (1930) as well as Hannon et al. (1966) found heart rate to increase sharply at first exposure to altitude, then to progressively decrease. Two weeks after subjects returned to sea level significantly depressed values were observed.[27,28] Dejours, Kellogg, and Pace (1963) reported exercise heart rate consistently higher in acute hypoxia than chronic hypoxia. Acclimatization tended to decrease the absolute heart rate during steady-state exercise. The increment in steady state exercise heart rate over the resting value fell progressively because of the rise in resting values. Heart rate values changed progressively during three weeks at altitude.[29] The relatively long time course of heart rate adjustment

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[26] John P. Hannon, Jimmie Shield, and Charles Harris, "High Altitude Acclimatization in Women," in R. F. Goddard (ed.) The International Symposium on the Effects of Altitude on Physical Performance, (The Athletic Institute, Chicago, 1966), p. 37.

[27] A. Grollman, "Physiological Variations in Cardiac Output of Man. The Effect of High Altitude on the Cardiac Output and Its Related Functions; an account of experiments conducted on the summit of Pikes Peak, Colorado, "Am. J. Physio., Vol. 93, pp. 19-40.

[28] Hannon et al., loc. cit.

[29] Dejours et al., loc. cit.

is not inconsistent with the relatively long time course of changes in cardiac output of sojourners at 14,000 feet described by Grollman (1930).[30] The cardiac output in Grollman's female subject began to increase on the third day at altitude. By the fifth day cardiac output had increased 100%, then subsided to 20-30% above previous sea level measurements. This pattern of response differs from that reported in men by Vogel et al. (1966) They reported essentially normal cardiac output values after three weeks exposure at the same site.[31] Grollman's measurements on himself concur with Vogel's findings in men, indicating a possible response difference in men and women.

Banchero et al. (1966) reported that in spite of hypoxemia of permanent residents at 15,000 feet the oxygen uptake, cardiac output, and stroke volume were similar to those found at sea level. These findings were associated with pulmonary hypertension which has been principally related to structural changes of the pulmonary vasculature. They added that variations in cardiac output and oxygen uptake are related to the intensity of work performed and are independent of the level of altitude. Elevated hemoglobin concentration in the natives of high altitude was of advantage to these people at rest, the arterial oxygen content was higher than the value obtained in sea level residents despite the arterial desaturation. With the same cardiac output similar amounts of oxygen can be transported

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[30] Grollman, loc. cit.

[31] J. A. Vogel, H. E. Hansen and C. W. Harris, "Cardiovascular Responses of Man During Rest, Exhaustive Work and Recovery at 4,300m.," (U.S. Army Med. Res. and Ntr. Lab Report, N. 294, 1966).

and delivered to the tissues with smaller changes in blood oxygen saturation. This is of special advantage during exercise when changes in blood oxygen saturation are smaller than the changes occurring at sea level in low altitude natives. While at altitude cardiac output increased during exercise as a result of increased heart rate, stroke volume remained constant.[32] Hecht (1968) stated an increase in right ventricular mass as well as moderate elevations of pulmonary artery pressure compared to sea level values was a normal finding in all species living at heights above 2,000 meters.[33] Several studies have commented on the increase in right ventricular mass. Among them Hultgren, Kelly and Miller (1965) reported three observations in natives living at elevations of over 12,000 feet: a) moderate enlargement of the right ventricle in roentgenograms of the chest, b) electrocardiograms demonstrating right ventricular hypertrophy patterns and c) moderate increase in the relative weight of the right ventricle as determined by autopsy study.[34] Yet Hecht (1968) claims there is no evidence that acute right heart overload due to excessive pulmonary hypertension occurs in man at any altitude.[35]

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[32]N. Banchero et al., "Pulmonary Pressure, Cardiac Output and Arterial Oxygen Saturation during Exercise at High Altitude and at Sea Level," Circulation, 33:249, 1966.

[33]Hans Hecht, "Certain Vascular Adjustments and Maladjustments at Altitudes," in E. Jokl (ed.), Medicine and Sport, Exercise and Altitude, (Basel, S. Karger, 1968), 134-147.

[34]H. N. Hultgren, J. Kelly, and H. Miller, "Pulmonary Circulation in Acclimatized Man at High Altitude," J. Appl. Physiol., 20 (2), 1965, p. 233-238.

[35]Hecht, op. cit., p. 143.

Hypertension and Glomeruli Enlargement

Naiye (1965) studied pulmonary and renal abnormalities in young children born at high altitude in the United States. Hypoxia appeared to arrest normal neonatal decrease of pulmonary arterial smooth muscle in some of these children. No abnormalities were found in pulmonary veins or capillaries.[36] Hultgren, Kelly and Miller (1965) also were concerned with pulmonary circulation. As a result of their study at La Oroya they concluded that there is no relationship between the hematocrit and the pulmonary hypertension or right ventricular hypertrophy.[37] Naiye (1965) thought it likely that the increased pulmonary arterial muscle mass present at high altitude is the cause as well as the consequence of the hypertension.[38]

A qualitative study by Naiye also demonstrated enlargement of renal glomeruli in hypoxic children after the first month of life, apparently due to proliferation of normal glomeruli elements. The renal glomerular changes found in the Leadville children resemble those found in children with cyanotic types of congenital cardial malformations.[39]

Tissue Level Adaptation

Cellular adaptation represents the deepest level in the hierarchy of adaptive functions of the body. In this process reorganization of the cell contents is necessary. Thus compared

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[36] R. L. Naiye, "Children at High Altitude; Pulmonary and Renal Abnormalities," Circulation Res., 16:33, 1965.

[37] Hultgren, Kelly, and Miller, loc. cit.

[38] Naiye, loc. cit. [39] Ibid.

to other functions of higher levels, such as circulation and respiration, longer time periods are required for the new steady state to be achieved. Adaptation on the cellular level is reflected in a normalization of functions at higher levels.[40]

The existence in high altitude natives, of certain tissue adaptive processes such as an increased action of the DPNH oxidase system and of mitochondrial transhydrogenase has been reported by Reynafarje (1961).[41] The glycolytic enzymes are not significantly involved in the adaptive processes to high altitude. Lactic acid level and the oxygen debt are lower in high altitude acclimatized man than non-acclimatized individuals after endurance tests. This is due to better utilization of lactic acid through the increased DPNH oxidase system and Pyridine nucleiotide transhydrogenase (Reynafarje and Velasquez, 1966; Tappan and Reynafarje, 1957).[42] Increased myoglobin content may serve as a link to maintain an optimal oxygen gradient between the cell plasma membrane and enzyme systems in the mitochondria (Vaughan and Pace, 1956).[43]

Grover (1963) reported a slight increase in BMR at high altitude. He speculated that this was due to acclimatization

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[40] W. H. Weihe, "Time Course of Adaptation to Different Altitudes at Tissue Level," Schweizerische Zeitschrift fur Sportmedizin, Vol. 14, p. 177.

[41] B. Reynafarje, "Pyridine Nucleotide Oxydases and Transhydrogenase in Acclimatization to High Altitude," Amer. J. Physio., 200:351-354, 1961.

[42] C. Reynafarje and Velasquez; Tappan and B. Reynafarje, quoted in W. H. Weihe, op. cit., p. 186.

[43] Vaughan and Pace, 1956, as quoted in Weihe, op. cit., p. 164.

to a lower ambient temperature or to a higher energy requirement with increased ventilation rate.[44] There is no increase of BMR at reduced partial pressure of oxygen under standard conditions as long as there is no increase in ventilation rate.

Weihe (1966) summarized acclimatization to altitude as depending on various climatic factors in addition to reduced air pressure, with adaptation at the tissue level as the final and decisive stage of acclimatization.[45]

Summary

In review, the principal findings reported on athletic performance at altitude have been that winning times of runners and swimmers have been systematically affected at middle altitude. The sprints were often run faster at altitude, while long distances were progressively slower.[46] Alternate exposure to altitude and sea level during a training program has been apparently a way to enhance the training effect for men not already in top form.[47]

Regarding the physiological basis for the performance findings, the decrease in maximum oxygen uptake as a function of altitude may not alone cause altered performance at altitude.[48] Metabolic adaptation implies a decreased buffer capacity. So, the final pH of the blood may be a factor limiting lactic acid

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[44] R. F. Grover, "Basal Oxygen Uptake of Man at High Altitude," J. Appl. Physio., 18:1963, pp. 909-912.

[45] Weihe, op. cit., p. 177.

[46] Jokl, loc. cit. [47] Balke, 1945, loc. cit.

[48] Craig, loc. cit.

production.[49]

On arrival at altitude one of the first changes noted has been an increase in ventilation.[50] Pulmonary hypertension and enlargement of the right ventricle has been reported in altitude residents.[51] Increased heart rate has been found at altitude. After an initial adjustment period of about three weeks cardiac output in men has returned to normal.[52] RBC count begins to go up within hours of arrival at altitude, hemoglobin values follow in their elevation. Total blood volume increases.[53]

Fluid loss from lungs may be large as a result of hyperventilation in the presence of dry mountain air, and so posterior pituitary and renal mechanisms are prompted to conserve water.[54]

Adaptation at the cellular level has been noted as the final phase of acclimatization. An increase in myoglobin content has been thought to aid an optimal oxygen gradient between the cell plasma membrane and the enzyme systems in the mitochondria.[55] Acclimatization to altitude involves both adaptation to climatic factors as well as reduced air pressure.[56]

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[49]P. Cerritelli, "Lactacid O_2 Debt in Acute and Chronic Hypoxia," in R. Margaria (ed.), Exercise at Altitude, 1967, pp. 58-64.

[50]Hornbein and Roos, loc. cit. [51]Hecht, loc. cit.

[52]Vogel, Hansen and Harris, loc. cit.

[53]Merino, loc. cit. [54]Hecht, op. cit., p. 136.

[55]Vaughan and Pace, 1956, as quoted in Weihe, loc. cit.

[56]Weihe, op. cit.

As this study is concerned with the performance of altitude dwellers at sea level, a summary of research on deacclimatization notes that Daniels and Oldridge (1970) found athletes arriving at sea level from higher elevations breathed more air for any given work intensity than they did prior to altitude exposure. This net hyperventilation was due to the cessation of the hypoxic drive coupled with the greater sensitivity of the respiratory center to CO_2 acquired at altitude.[57] Although Balke (1964) and Bynum (1966) concluded that natives of high altitude show an increase in work capacity upon descending to a lower altitude,[58,59] Grover and Reeves (1966) and Daniels and Oldridge (1970) failed to find performance improvement under similar circumstances.[60,61]

Studies concerned with deacclimatization indicate that it is a major transient taking some time to complete. For example, Reynafarje (1959) found that it took 100-120 days for the RBC and Fe turnover rate to reach about the normal rate.[62] And, Dejours, Kellogg, and Pace (1963) have shown that the return of the CO_2 sensitivity of the respiratory center to normal after return of the individual to sea level from altitude, required about thirty days to be completed.[63]

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[57]Daniels and Oldridge, loc. cit.

[58]Balke (1965), loc. cit. [59]Bynum, loc. cit.

[60]Grover and Reeves, loc. cit.

[61]Daniels and Oldridge, loc. cit.

[62]Reynafarje, (1959), loc. cit.

[63]Dejours, Kellogg, and Pace, (1963), loc. cit.

Chapter 3

METHODS AND PROCEDURES

Female students at South Tahoe Intermediate School ran three times a week during their Physical Education class. Distances of 400m., 800m., and one mile were alternately run. The fastest five girls in each class every day were recorded, and after three weeks of training, volunteers were asked for from the select group. Ten subjects were chosen from the volunteers, mainly on the basis of their responsibility. After one testing session two of the subjects dropped out; one because of difficulties with auto sickness, and the other because the father thought the distance between testing cites too far. The girls ranged in age from 12 to 14, and in weight from 75 to 130 pounds. All were premenarche but two. During the testing program they continued in the school fitness program, running a mile once a week, 800m. once a week and 400m. once a week. Sprints or hurdles were also practiced one day a week. All but one of the subjects also participated in school track meets.

Training prior to testing could not begin earlier than the three weeks because of snow on the ground and track. Testing could not start later because the subjects would be out of school and families would be planning vacations. Eight Saturdays in April and May were scheduled for testing at a 400 meter Tartan track at South Tahoe Intermediate School, elevation 6256; and a 440 yard All-weather track at the College of Marin in Kentfield, California, elevation approximately sea level. There were four test days at each level of altitude. Repeated measures were used to increase reliability. The testing schedule was varied so that a session at altitude did not always precede a session at sea level. Fingertip blood samples for the microhematocrit were taken at one pm each day of testing. This was done right after a simple lunch and prior to the performance testing which was done generally between two and four pm. Refrigerating the blood samples was considered unnecessary because the capillary tubes were treated with heparin. However, after the samples were taken they were stored until the following Monday. At that time they were centrifuged and read in a physicians office at South Lake Tahoe.

Each Subject kept her own menstrual records on a two month calendar that was given her for that purpose.

Temperature and humidity recordings were made each day of testing between two and three pm. A homemade sling psychrometer provided this information. Barometric pressure was recorded from readings taken at the South Lake Tahoe Airport tower and at Hamilton Air Force Base. In order to reduce the corrected figures from the Lake Tahoe tower to represent the actual pressure of the inspired air, 1 in. Hg. per 1,000 ft. elevation must be subtracted from the pressures the tower reported. The Pollution Control Board Office in San Francisco provided the air pollution index for each day of sea level testing. Their index was based on a scale designating 0-30 as clean air, 30-50 moderate, 50-75 severe and 75-100 heavy pollution.[1]

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[1]Information Bulletin Combined Pollutant Index Experience 1969 included in Appendix.

The equipment needed for the performance testing was a Wilson 100 foot metal measuring tape and an Apollo stop-watch which was taken to the Jewelers for calibration just prior to the first testing session.

Every subject participated in every one of the variables. Each subject was tested alone without competition, and all times were taken by the same timer on the same watch. The girls had been instructed to do their best at all times, and on the longer distances they were instructed to pace themselves to get the best time without being absolutely exhausted before the finish.

Testing sessions began with a limited warm-up; fifty jumping jacks, fifty mountain climbers and thirty ankle rotations for each foot. Then, quickly one by one the girls ran the 50 yard dash. Again in the same order they ran the 440. As each girl finished the 440 she went to another area to do her softball throw. Each subject took three throws during each testing session. A partner checked the best throw against the steel tape, and its distance was recorded to the nearest one half foot. As each girl finished her softball throw she returned to the track for the 880 yard run. It usually took between an hour and a half to two hours to complete the testing each day.

There were five dependent variables--(a softball throw, 50 yard dash, 440 yard dash, and an 880 yard run, also a hematocrit). The independent variables were the two altitude levels. A 2 x 4 factorial design was used with repeated measures on each dependent variable. The dependent variables were chosen because:

1. It has been previously found that short runs and throws are

improved at moderate altitude.

2. Long runs are impaired at altitude, but intolerable atmospheric conditions may also cause impairment.

3. These performance events represent performances in a track meet.

4. The blood determinations imply the adaptation to altitude.

For analyzing the data statistically, five anovas were used. One manova was an alternate choice which would have reduced the type I error rate. However, the statistics were calculated by hand rather than by computer. Using anovas would make computing and interpreting the data easier. To aid interpretation, temperature, humidity and barometric pressure were recorded at each testing session. The air pollution index was also noted in the metropolitan area of sea level testing. Comments on the winds were jotted on the data sheets. Menstruation records were kept by the subjects in order to have more information relating to the hematocrits. Any physical complaints of the subjects on testing days were also noted.

On the following page is a diagram depicting the 2 x 4 factorial design with its 5 dependent variables.

Table I

Indep.		ALTITUDE 6,256 ft.				SEA LEVEL				
		1	2	3	4	1	2	3	4	
testing order		(1)	(3)	(6)	(8)	(2)	(4)	(5)	(7)	temp., humidity, barometric pressure recorded at each trial
dep.	S1									
	2									
	.									
softball throw	.									
	.									
	8									
	S1									
	2									
	.									
50 yd. dash	.									
	.									
	8									
	S1									
	2									
	.									
440 yd.	.									
	.									
	8									
	S1									
	2									
	3									
	.									
880 yd.	.									
	.									
	8									
	S1									
	2									
	.									
Hematocrit	.									
	.									
	8									

Menstruation records, pollution index, winds, health notes were added incidental information.

The source of variance for each Anova is tabled below.

Table II

ANOVA TABLE

source	d.f.
subjects	7
treatments	7
altitude	1
trials	3
alt. x trials	3
error	49
sub. x alt.	7
sub. x trials	21
sub. x alt. x trials	21
total	63

When a significant trials effect was found a post hoc trend analysis was then computed.

The predictions were that the four trials at altitude would show steady improvement due to training and learning. The four trials of the softball throw, 50 yard dash and 440 yard run would be impaired at sea level, but would improve over the four trials. It was also predicted that the 880 yard run on the first sea level test would be on a par or better than the average of the altitude trials, but would become impaired as summer weather arrived. The hematocrits were expected to remain fairly constant over the testing period, but would vary considerably between subjects.

Chapter 4

RESULTS AND DISCUSSION

Results

An examination of the test results was made in order to help determine if the athletic performance of middle altitude dwelling girls is actually impaired at sea level.

For the 880 yard run, times at sea level were on an average faster than at altitude. But, the difference was not sufficient to permit the effect of altitude to be considered significant. The four treatments at sea level were not consistently faster than the four treatments at altitude. For example, the second altitude runs were faster than the second sea level runs. The second sea level runs proved to be, in fact, the slowest 880 times recorded at sea level. By pairing each sea level treatment with its corresponding altitude treatment, scores for four trials were calculated. There was a significant effect between these trials at better than the one percent level of significance also. The improvement noted from trial to trial was a significant linear trend. As had been predicted, the first treatment at sea level was better than the previous treatment at altitude. Joint effects of trials and altitude were significant at the one percent level of significance.

Figure 1

880 Yard Treatments

Figure 2

880 Yard Run - Trials

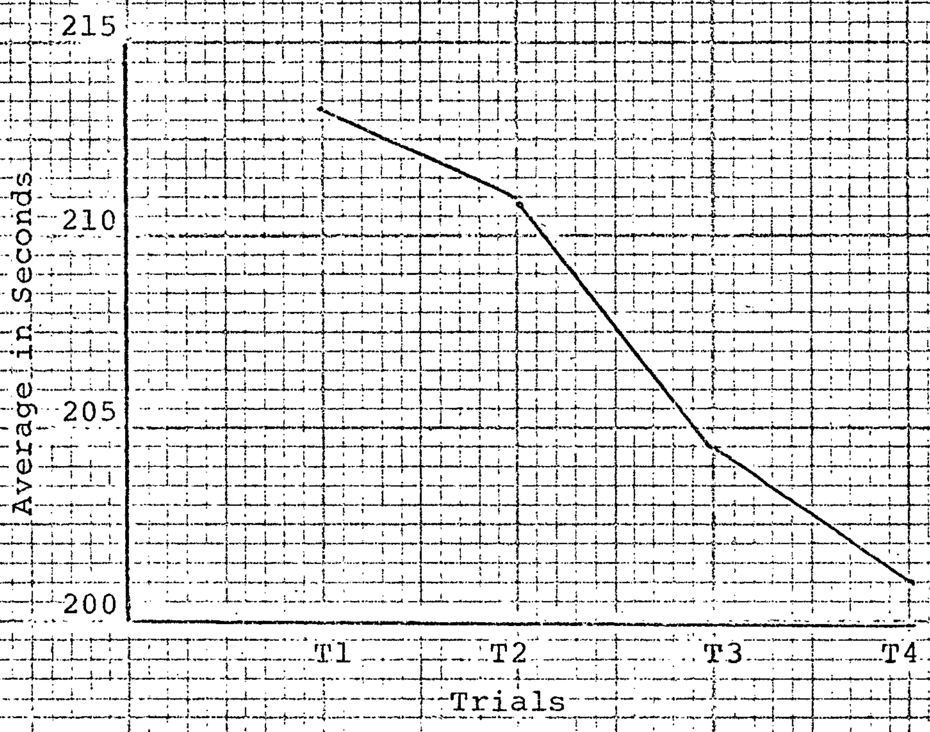

Table III

880 YARD RUN ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	18740.21	7	2677.17		
Treatments	2513.57	7	359.08	5.72	sig. 1%
trials	1536.66	3	512.22	6.87	sig. 1%
linear	1497.31	1	1497.31	20.08	sig. 1%
altitude	182.3	1	182.3	2.71	no sig.
trials x alt.	794.60	3	264.87	5.37	sig. 1%
Error	3072.3	49	62.7		
sub x alt	471.33	7	67.33		
sub x trials	1565.57	21	74.55		
sub x trials x alt	1035.39	21	49.30		
Total	24326.08	63	3861.44		

F .05 4.04
.01 (1,49) 7.18

F .05 3.07
.01 (3,21) 4.87

F .05 4.32
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

Figure 3 illustrates the trend of the trials for the 440. The third trial was the slowest but the fourth was the fastest. To explain this, a look at individual treatments points out the third treatment at sea level was slower than the first treatment at altitude. The fourth treatment at altitude, which was the last in the testing schedule was the best of all treatments at either altitude or sea level. Again there was no significant difference between sea level and altitude performance, although the total times at altitude were faster than total times at sea level.

There was a significance interaction of altitude x trials at the one percent level. Factors affecting performance at the two levels of altitude were not consistent or the same. As performance improved at altitude it became worse at sea level and vice versa.

As in all the other variables, the subjects proved to perform significantly different from one another on the 50 yard dash. The only significant statistic was the altitude effect. And, here the female subjects were faster at the sea level track, with only a five percent chance that this difference was not truly due to the differences found at the two altitude conditions. The subjects were consistent in their efforts. On such a short run some subjects varied only one tenth of a second in all treatments at a single track. With such consistency, the subjects did not appear to get better at this event as the testing program proceeded. In fact, the best

Figure 3

440 Yard Dash - Trials

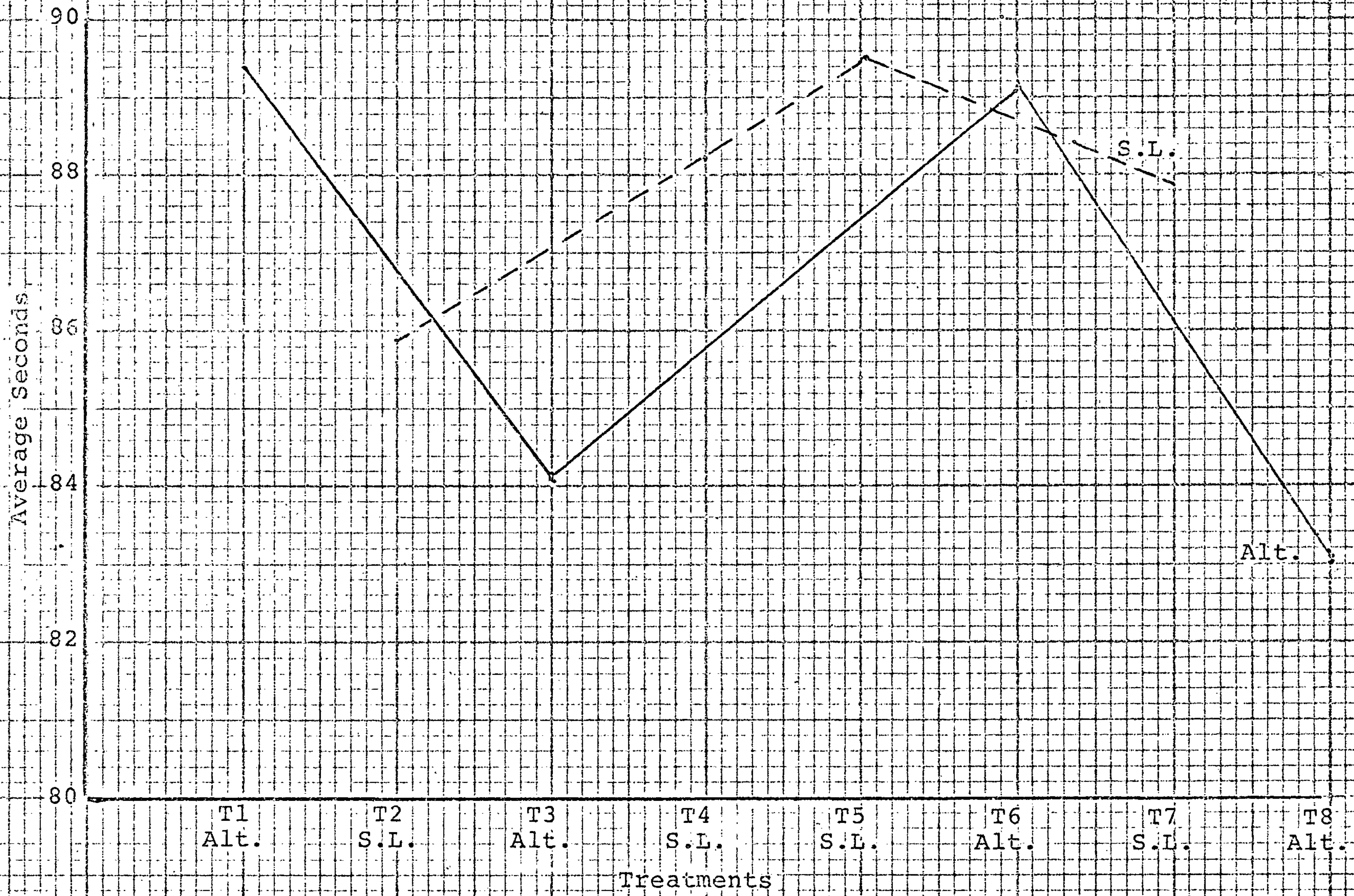

Figure 4

440-Yard Dash - Treatments

Table IV

440 Yard Dash Anova Table

Source	SS	d.f.	ms	F	p
Subjects	3408.66	7	486.95		
Treatments	340.31	7	48.61		
trials	139.88	3	46.63	2.16	no
linear	10.98	1	10.98		
quad.	4.82	1	4.82		
cubic	104.76	1	104.76	4.80	sig. 5%
Altitude	31.50	1	31.50	2.79	no
Alt. x trials	168.92	3	56.30	15.06	sig. 1%
Error	610.81	49	12.46		
sub x alt	78.87	7	11.26		
sub x trials	453.38	21	21.59		
sub x trials x alt	78.55	21	3.74		
Total	4359.79	63	69.20		

F .05 4.04
.01 (1,49) 7.18

F .05 4.32
.01 (1,21) 8.02

F .05 3.07
.01 (3,21) 4.87

F .05 5.59
.01 (1,7) 12.25

times were recorded on the first test at sea level.

For the softball throw almost random results were attained, particularly from the sea level tests. For sure, the subjects differed, with the best thrower almost doubling the distance of the worst. The effect of trials x altitude was significant at the five percent level. Despite the average length of throw being further at altitude than at sea level, statistically the effects of altitude were nil. Improvement was steadily made at altitude, while such improvement was not so noticeable at sea level. No significance was found in the interactions.

As expected, hematocrits were statistically without difference at altitude and sea level. Trials showed no significance at the five percent level, but trials x altitude did. A trend analysis was not performed, but a scrutiny of the data revealed no pattern to the percent hematocrits recorded. A comparison of the two subjects menstrual records to their hematocrits revealed no particular peaks or dips in the hematocrits parallel to monthly rhythms. The lowest recorded hematocrit was a 39.5%, the highest was a 49.5%. The average of all recordings for all the girls was 43.9%. Averages for females at sea level are about 39%. The average for 100 females in Mexico City was 45.5%.[1]

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[1]P. Altman, Blood and Other Body Fluids, Federation of American Societies for Experimental Biology, 1961, p. 192.

Figure 5

50 Yard Dash - Treatments

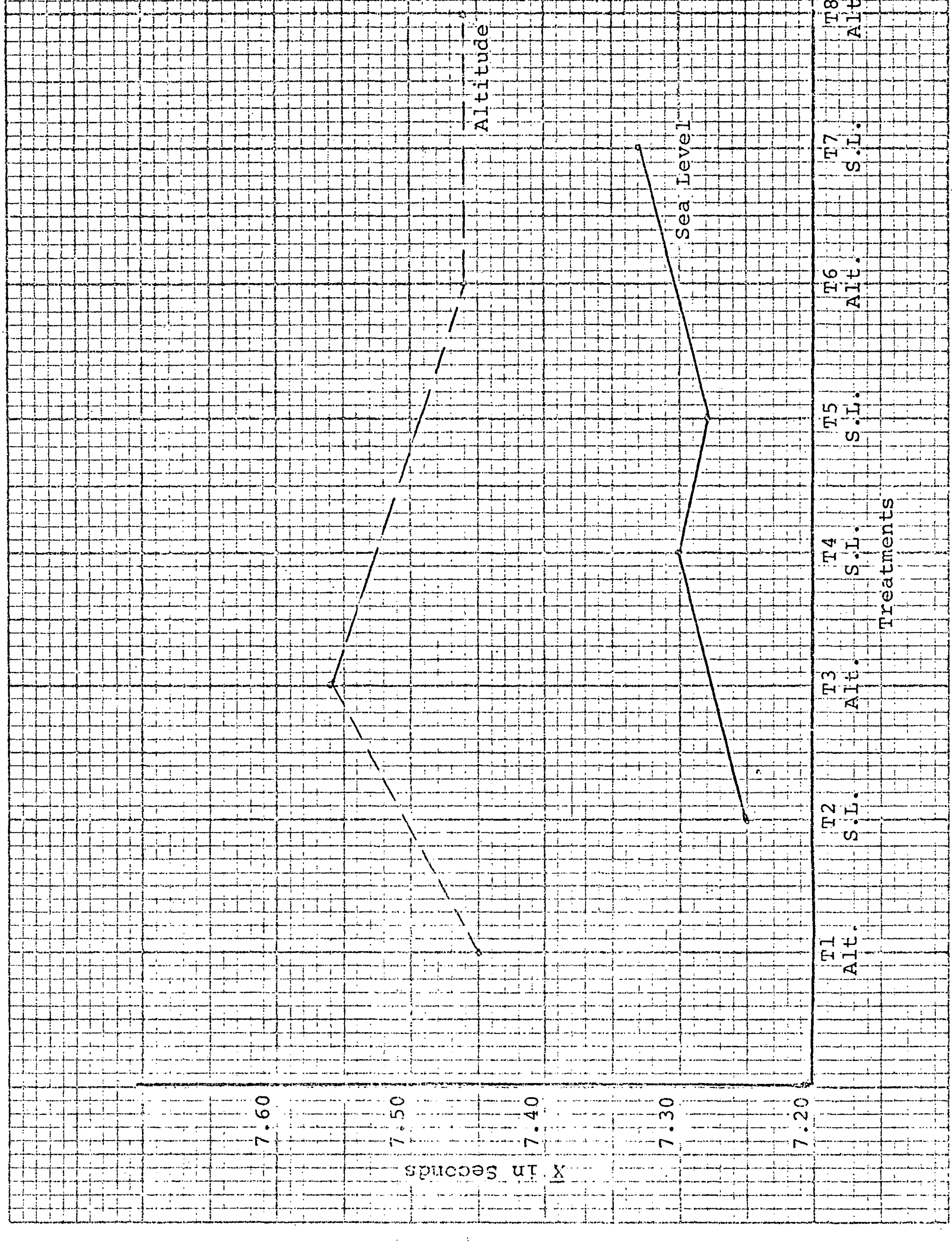


Table V

50 YARD DASH ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	9.06	7	1.29		
Treatments	.68	7	.09		
trials	.06	3	.01	2.53	no
altitude	.58	1	.58	6.83	sig. 5%
alt. x trials	.039	3	.013	0.46	no
Error	1.36	49	.027		
sub x alt	.59	7	.085		
sub x trials	.16	21	.007		
sub x trials x alt.	.60	21	.028		
Total	11.10	63	.18		

F .05 2.21
.01 (7,49) 3.03

F .05 3.07
.01 (3,21) 4.87

F .05 4.34
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

Figure 6

Softball Throw - Treatments

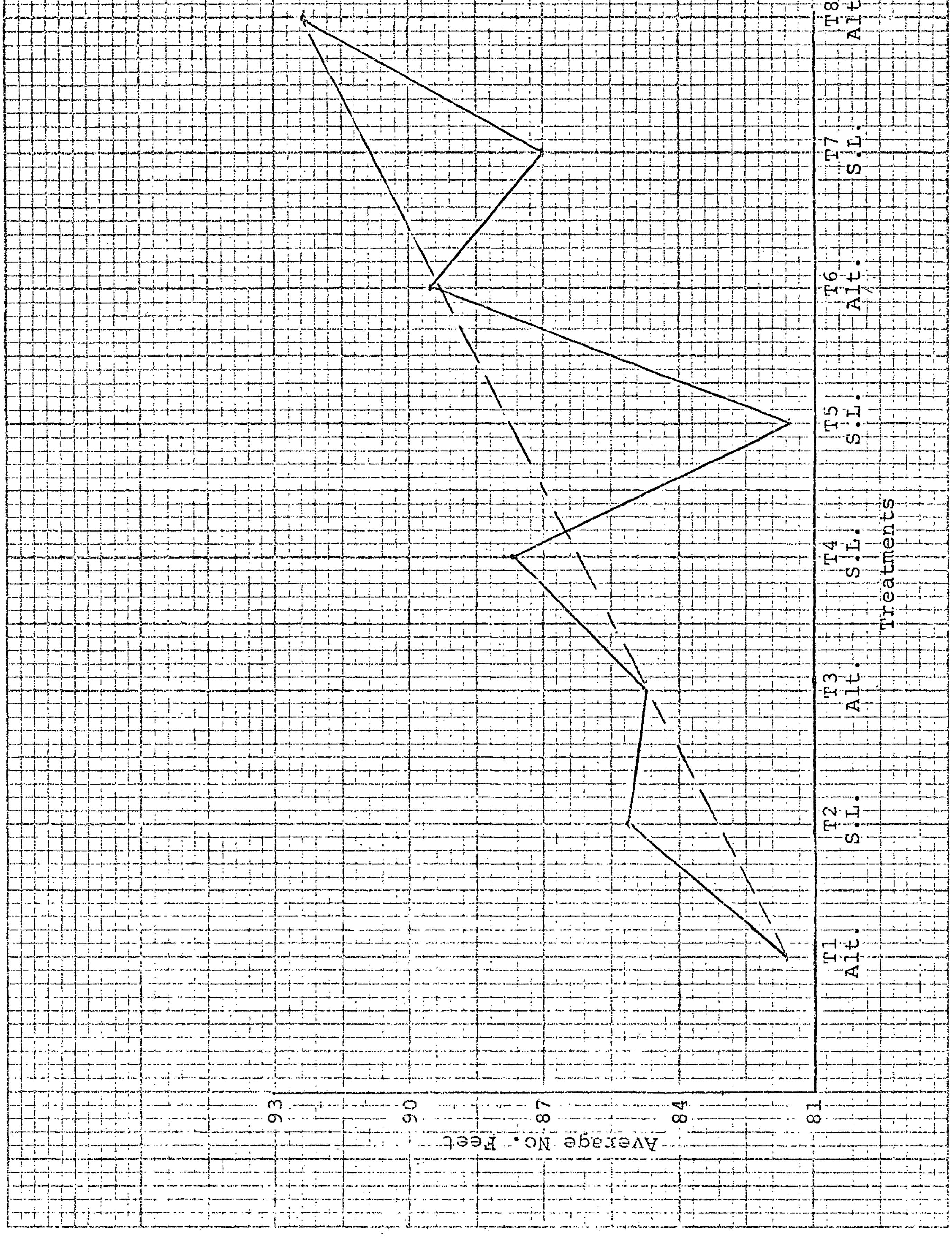


Table VI

SOFTBALL THROW ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	29182.31	7	4168.90		
Treatments	792.62	7	113.23		
altitude	38.28	1	38.28	1.96	no
trials	322.17	3	107.38	2.01	no
trials x alt.	432.16	3	144.056	4.06	sig. 5%
Error	2005.03	49	40.92		
sub x alt	136.81	7	19.54		
sub x trials	1123.61	21	53.50		
sub x trials x alt.	744.61	21	35.45		
Total	31979.96	63	507.61		

F .05 2.21
.01 (7,49) 3.03

F .05 3.07
.01 (3,21) 4.87

F .05 4.32
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

The air temperature during the altitude sessions progressed from 51° to 66°F, while the sea level sessions followed this order; 82°, 72°, 60°, 66°F. The first altitude session was cold, dry, and windy. A wet bulb reading of only 38°F was taken, hence relative humidity was only 23%. As a contrast the first sea level session was hot and still. The pollution index that day was 30, humidity 30%.

All of the subjects had headaches during the first sea level test, but the indisposition did not seem to affect performance. In fact, the subjects appeared excited about doing the tests. Three subjects experienced severe side aches or stomach cramps during the last three times they ran the 880. The youthfulness and inexperience of the subjects sometimes made it difficult to get an accurate description of their feelings.

DISCUSSION

Post hoc examinations of world records at sea level and altitude have shown times to be systematically affected by altitude. True experiments have realized similar results. Since Jokl claimed the handicapping influence of the lowered oxygen pressures becomes statistically valid at 5,350 feet for distances of 1,500m. and longer; and at 7,340 feet for distances 800m. and longer, it was expected that the times in this investigation at 6,256 of the 880 yard run would be statistically

Figure 7

Hematocrit - Treatments

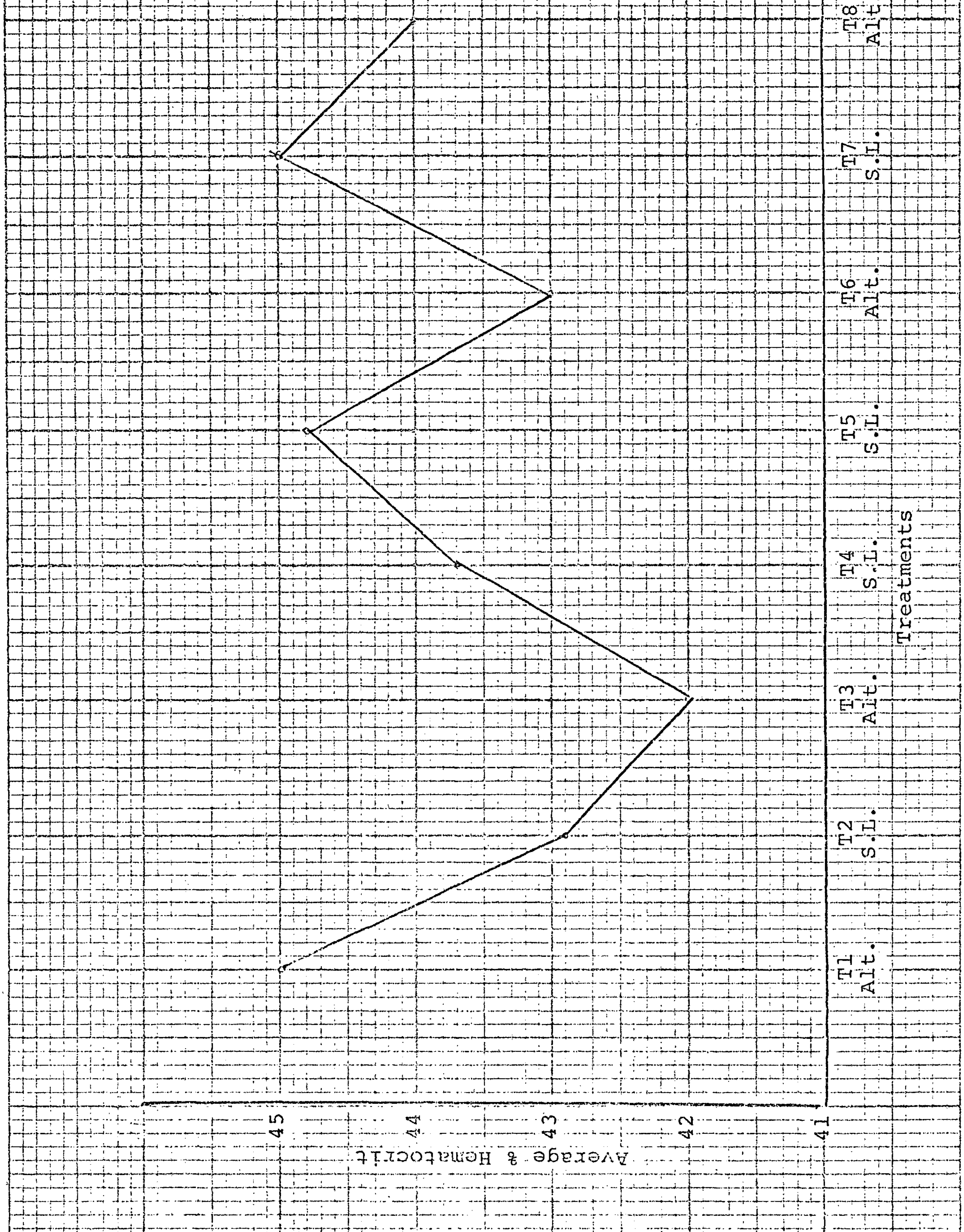


Table VII

HEMATOCRITS AND MENSTRUAL RECORDS

2 APRIL subject 2	3	4	5	6	7	8 46.5%	alt
9	10	11	12	13	14 /	15 / 49%	s.l.
16	17	18	19	20	21	22 42%	alt
23	24	25	26	27	28	29 / 46%	s.l.
30 /	1 MAY	2	3	4	5	6 49%	s.l.
7	8	9	10	11	12	13 42%	alt
14	15	16	17	18 /	19 /	20 47%	s.l.
21	22	23	24	25	26	27 48.5%	alt

2 APRIL subject 9	3	4	5	6	7	8 45%	alt
9	10	11	12 /	13 /	14 /	15 / 46%	s.l.
16 /	17 /	18 /	19	20	21	22 42.5%	alt
23	24	25	26	27	28	29 42.5%	s.l.
30	1 MAY	2	3	4	5	6 47%	s.l.
7	8	9	10	11	12	13 42.5%	alt
14 /	15 /	16 /	17 /	18 /	19 /	20 45%	s.l.
21	22	23	24	25	26	27 43.5%	alt

Table VIII

HEMATOCRIT ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	190.46	7	27.21		
Treatments	57	7	8.14		
trials	16.03	3	5.34	1.85	no
altitude	3.07	1	3.07	0.73	no
alt x trials	37.89	3	12.63	3.60	sig. 5%
Error	163.78	49	3.34		
sub x alt	29.58	7	4.22		
sub x trials	60.50	21	2.88		
sub x alt x trials	73.69	21	3.50		
Total	411.25	63	6.52		

F .05 2.21
.01 (7,49) 3.03

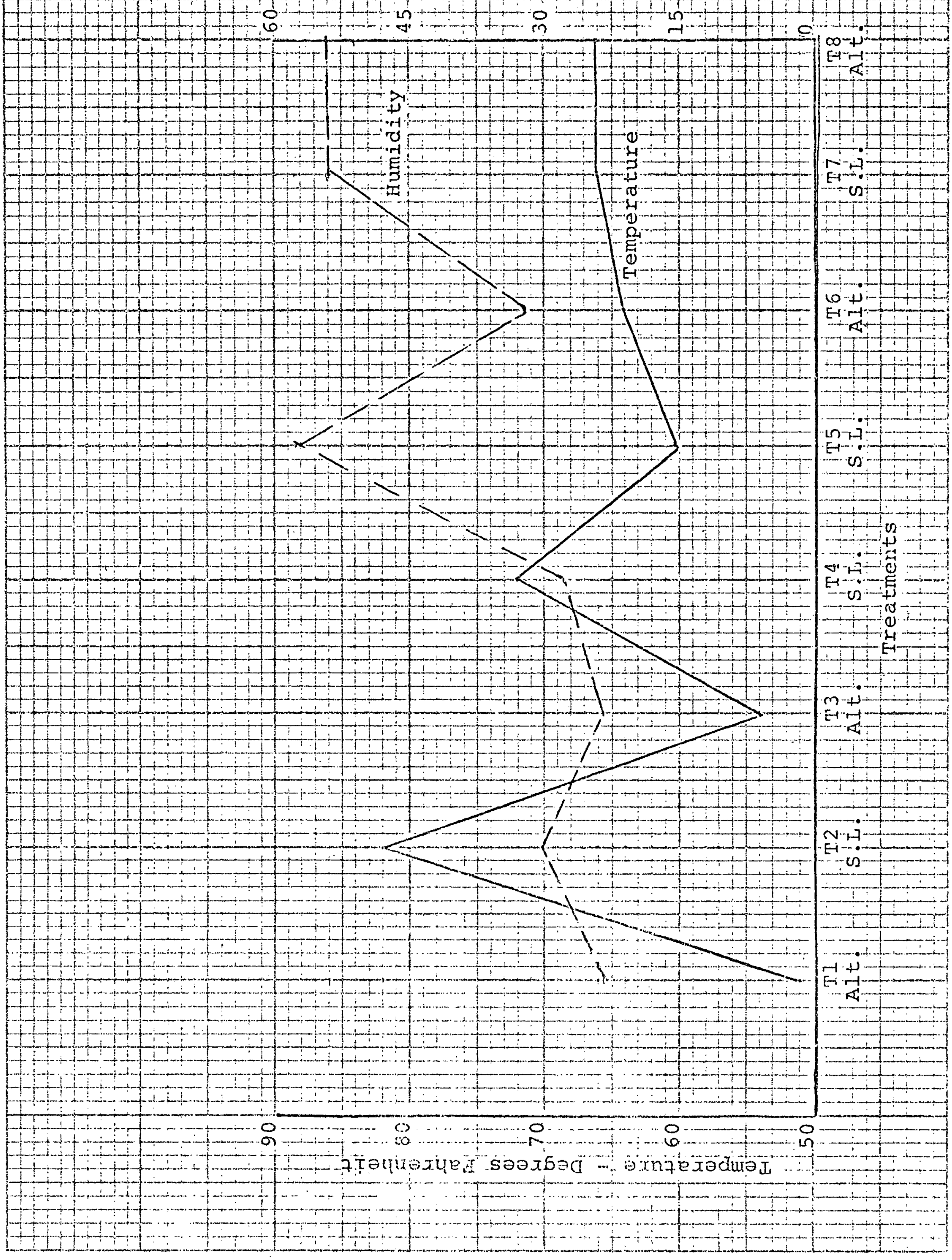
F .05 3.07
.01 (3,21) 4.87

F .05 4.32
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

Figure 8

Temperature and Relative Humidity Graphed



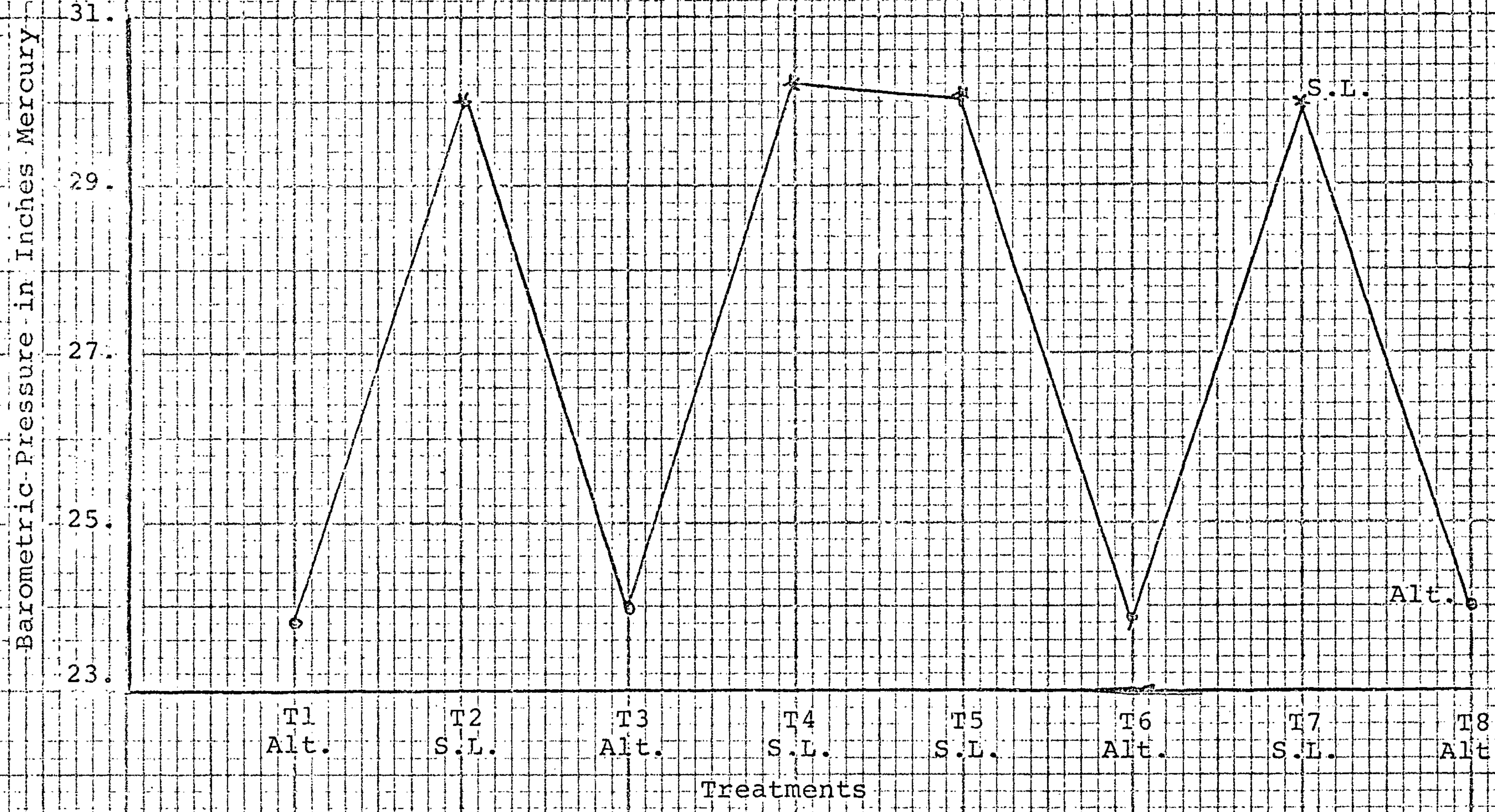


Figure 9

Barometric Pressure over Treatments

slower at altitude. This prediction did not quite hold up. Although average running times were slower at altitude, a Fisher ratio of 2.9 with one degree of freedom does not make this difference significant. When results are graphed, it appears that at altitude fairly steady improvement took place, while at sea level total test scores were erratic; sometimes better than previous altitude tests, but not always. The subjects were involved in a mild training program throughout the two months of testing. So, as long as testing conditions remained pleasant there should have been performance improvement. Continued running experience would increase oxygen uptake, and pacing techniques would become refined. The improvement that was noted in the data was probably the result of this happening.

The large difference in times taken at the first treatment at altitude and the first treatment at sea level must be in part accounted for by the emotional excitement of traveling to the sea level test site and the special attention newly afforded the subjects. For most of the girls this was as far as they had ever traveled before, and probably many had never been so far from their families. The sea level track was situated in a complex of other recreational facilities, all impeccably maintained and very impressive. This new and special treatment stimulated the girls to producing some of their best times so far. In addition, the day of the first sea level tests was hot for individuals who had just come from snow at their mountain home. The warmth of the day possibly increased metabolic processes and hence aided running times.

The significant interaction of trials and altitude that occurred in both the 880 and 440 run may be difficult to interpret. On improvement from trial to trial that occurred in part because of a change in altitude Daniels and Oldridge (1970) also had to comment.

> There is also a possibility that the desire at altitude to equal normal sea-level performance motivated the subjects to push closer to max VO_2 for a longer period of time than normal, an attitude they carried over into post-altitude runs. If so, then training at altitude would benefit subsequent sea-level performance as the runners attained an ability to withstand more discomfort than usual. This would presumably be reflected by greater utilization of the anaerobic capacity in altitude and post-altitude runs, a possibility not investigated.[1]

The 440 yard dash being a middle distance for young girls or a lengthy sprint, and considered extremely taxing in competition was expected to be a balance point in this experiment. Times were predicted to be only slightly better at altitude than sea level, but showing the effects of training from start to finish. These predictions were fairly accurate. Astrand (1970) wrote that with a work time of up to two minutes the anaerobic power is more important than the aerobic; at about two minutes there is a 50:50 ratio, and with longer work time the aerobic power becomes gradually more dominating.[2] The subjects 440 times ranged from 1:14.8 to 1:46.1, so for the most part anaerobic power was more important, but for some the 50:50 mark was close.

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[1]Jack Daniels and Neil Oldridge, "The Effects of Alternate Exposure to Altitude and Sea Level on World-class Middle-Distance Runners," Medicine and Science in Sports, (Fall 1970), Vol. 2, No. 3, p. 111.

[2]Per-Olof Astrand, Kaare Rodahl, Textbook of Work Physiology, (McGraw-Hill Book Company, N.Y., 1970), p. 304.

Grover and Reevés (1966) found some of their male subjects performing this event better at sea level, others at altitude.[3] On an average the girls in this experiment ran the 440 faster at altitude, but with a Fisher ratio of 2.5 and 1 degree of freedom this difference could not be considered significant. Improvement was generally noted from start to finish. (One subject became progressively slower). The more this distance was run at full effort, the greater was the mechanical efficiency, and tolerance of lactic acid in the muscles increased. Astrand (1970) has said "the highest blood lactate values so far are in samples drawn from well-trained athletes at the end of competitive events of one to two minutes duration...during training, the blood lactate concentration for a given work load is lower, but the values attained during maximal physical effort are usually higher."[4]

During treatments 4, 5, 6, 7 there was a slump in performance. This may have been the result of a psychological low. During the second and third treatments there was the thrill of a new experience and travel. The last treatment was the last chance to better all previous times.

With the results of the 50 yard dash producing a surprise reverse of previous studies, a look at all influencing factors must be made. First of all, did changes in altitude really make a substantial change in air pressure? To answer

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[3]Robert Grover, John Reeves, "Exercise Performance of Athletes at Sea Level and 3,000 meters Altitude," The International Symposium on the Effects of Altitude on Physical Performance, (1966), p. 80.

[4]Astrand, op. cit., p. 298.

that, the pressures at altitude averaged 79% of the pressures recorded at sea level. An important consideration is the fact that at the altitude track the subjects faced into the prevailing air currents, while at sea level the 50 yard dash was run with the wind. It also seemed that when air temperature was really warm, better results were achieved. The 50 yard dash was the first test administered during each testing session. The degree of success in this event more than the others was related to effectiveness of the warm-up and body core temperature. Since the warm-up was the same at each testing session it was less effective in 51° weather than in 82° weather. At a higher temperature metabolic processes in a cell can proceed at a higher rate, since these processes are temperature dependent. The exchange of oxygen from the blood to the tissues is faster at a higher temperature. A reduction in conductance of the tissue occurs when the skin is chilled. This is partly because of vasoconstriction of the skin's blood vessels causing a reduction in blood flow, and partly because the blood in the veins of the extremities is detoured from the superficial to the deep veins.[5] Furthermore, the nerve messages travel faster at higher temperatures.[6] Hobert and Lynggren (1947) examined the effects of active and passive warm-up on the speed of running. In the 100m. dash the improvement after a proper warm-up was in the order of 0.5 to 0.6 seconds, corresponding to three to four

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[5]Astrand, op. cit., p. 224.

[6]Astrand, op. cit., p. 496.

percent compared with the results without any warm-up.[7] This information would point out that the warm-up employed was evidently insufficient for performing the 50 yard dash optimally in the cooler temperatures.

It would be foolish to try to presume which were more important, barometric pressure or temperature, to the 50 yard dash performance. The two factors are mutually dependent weather wise. They were uncontrollable by the experimenter. Previous studies which have controlled these factors did not lend insight into coaching strategy. A coach cannot control barometric pressure, but he can prescribe warm-ups and pre-competition activity in correct dosages considering his athletes and the temperatures of the day.

Reports vary on the effects of altitude upon jumping and throwing events. Jokl has praised Bob Beamon's record long jump at Mexico City. One of the factors he attributes for making this record jump possible was the reduced air resistance at the altitude of Mexico City.[8] Reduced air resistance should be a factor in throwing events as well. Astrand (1970) has stated that with the force of gravity reduced at a greater distance from the earth's surface there may be a favorable effect in the case of athletic events involving jumping or throwing at high altitudes.[9] Cervantes and Karpovitch (1964) in a report on

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[7]Hoberg and Lyndgren (1947) as quoted in Astrand, op. cit., p. 496.

[8]Ernst Jokl, "A Report on Bob Beamon's World Record Long Jump, and His Subsequent Collapse at Mexico City, October 18, 1968," The Physical Educator, (May 1970), p. 69.

[9]Astrand, op. cit., p. 563.

Figure 10

Barometric Pressure and 50 Yard Dash over Trials

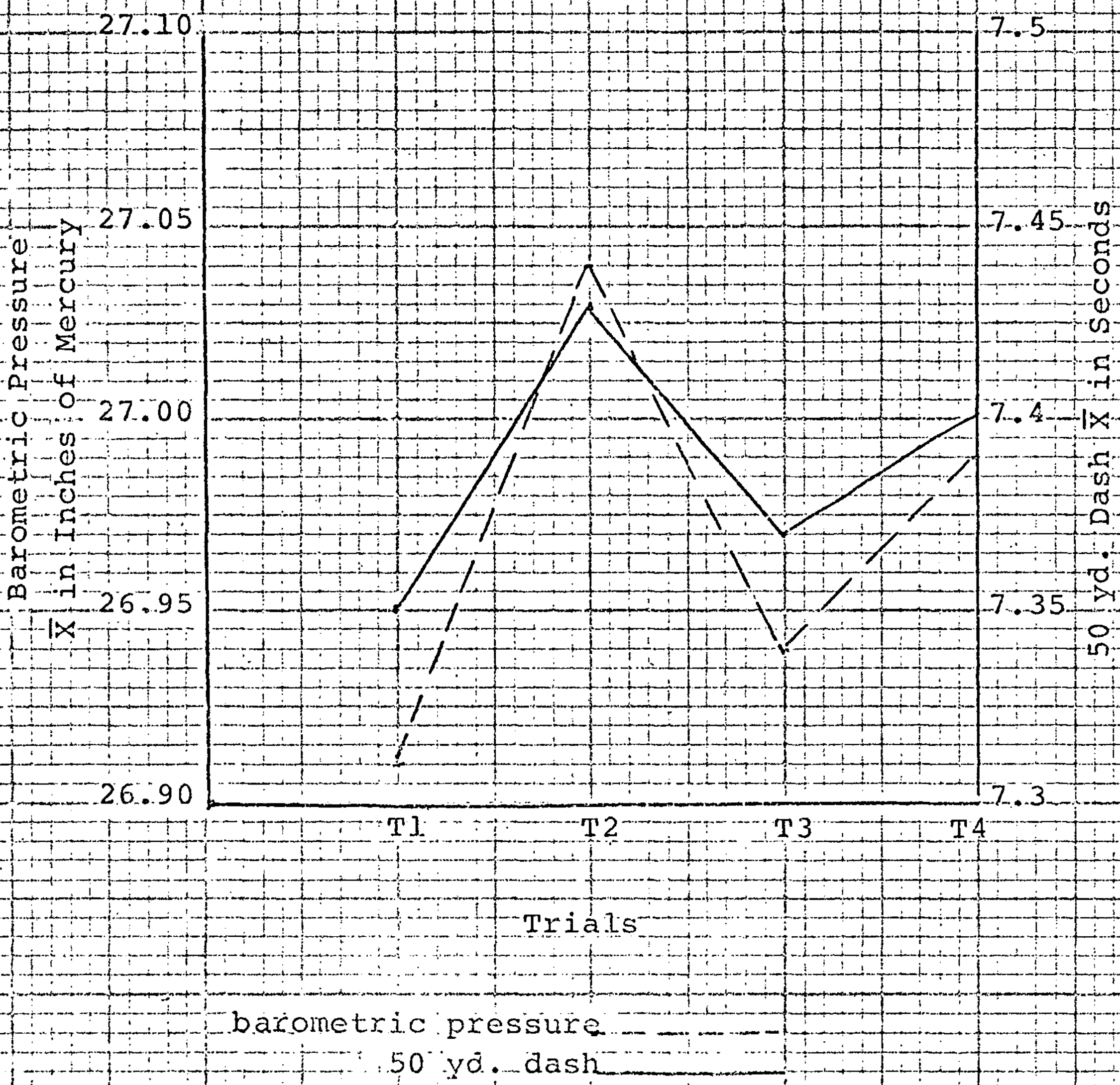
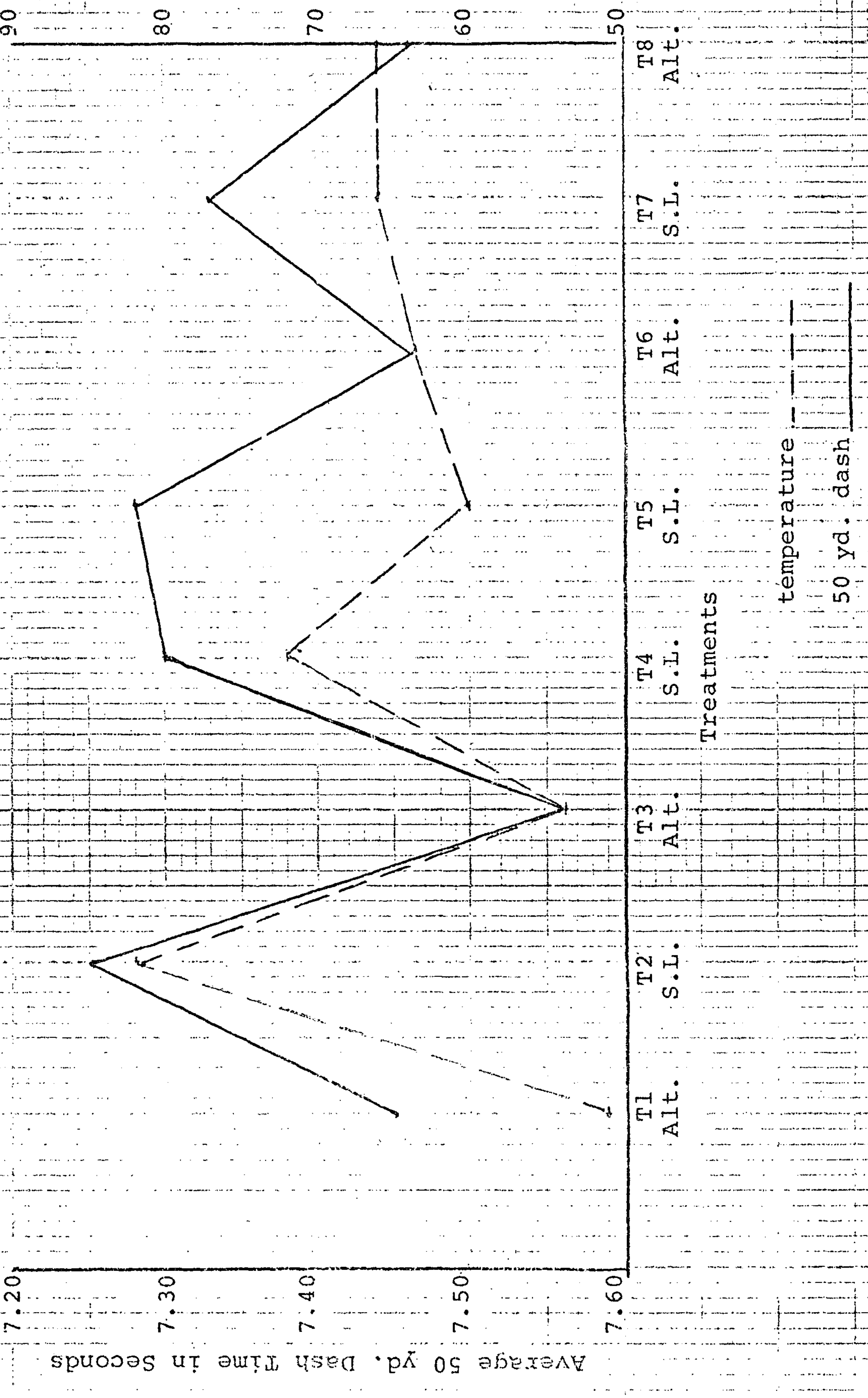


Figure 11

Temperature and 50 yd. Dash over Treatments



the effect of altitude on athletic performance stated that field event results have been inconsistent.[10] The effects of altitude upon throwing were not significant in this experiment. The throws at sea level were erratic from testing session to testing session. For one thing, during the first session at sea level throwing was done on a packed earth surface and at the following sessions throwing was done on greens such as was the case at altitude. Perhaps another reason for erratic performance was the fact that several of the girls did not throw very well and were learning the proper skill sequence. Fitts and Posner (1967) referred to the second stage of skill learning as the phase when error, wrong sequences of acts and responses to wrong cues are gradually eliminated.[11] The learning process was more consistent at the altitude location, the place where they were accustomed to throwing and learning.

As expected hematocrits varied among the subjects within the normal range. Healthy individuals differ widely with respect to blood formulas. These differences are associated, to a small extent, with individual differences in body weight, stature and surface area, the red cell count, hemoglobin and volume of packed red cells tending to be higher in heavier and taller individuals. Despite the fact that most of these girls were premenarche their hematocrit average was more typical of women living at moderate altitude than men. Wintrobe (1961)

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[10]J. Cervantes, P. V. Karpovitch, "Effect of Altitude on Athletic Performance," Research Quarterly, (1964), Vol. 35, 3 (2), pp. 446-448.

[11]Paul Fitts, Michael Posner, Human Performance, (Wadsworth Publishing Company, Belmont, Calif., 1967), p. 12.

stated it is noteworthy that the difference in red corpuscles between males and females does not become manifest until puberty.[12] No relationship was noted between subjects menstrual cycles and hematocrits, but the sampling was small. Wintrobe (1961) has commented that it has not been shown conclusively that there is any correlation between normal menstrual periods and fluctuations in the erythrocytes or hemoglobin. Although, a premenstrual decrease has been observed in some women possibly as a manifestation of hydremia which sometimes precedes the onset of menstruation.[13]

Some subjects did have higher hematocrits at sea level than altitude. This concurs with graphs in studies by Reynafarie (1959) and Merino (1950) which also showed a rise sometimes immediately on arrival at sea level and prior to the decrease that follows.[14,15] Although, the literature is lacking in an explanation, it is reasoned that subjects became somewhat dehydrated during travel. A reduction in plasma fluid would then elevate the percent of cellular matter.

Because temperature, humidity, barometric pressure, winds and air pollution were uncontrollable, such weather data was recorded only for the purpose of lending additional insight into the results. Due to the uncontrollability of these factors

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[12]Maxwell Wintrobe, Clinical Hematology, (Lea & Febiger, Philadelphia, 1961), p. 107.

[13]Ibid.

[14]C. Reynafarje, "The Polycythemia of High Altitudes: Iron Metabolism and Related Aspects," Blood, 14, 1959, 433-455.

[15]C. Merino, "Studies on Blood Formation and Destruction in the Polycythemia of High Altitudes," Blood, 5, 1950, 1-32.

Table IX

HEMATOCRIT VALUES[16]

All subjects were residents of the given locale.

	Altitude m	Country	Place	No. of subjects	Hematocrit ml RBC/100 ml blood
1	395	Peru	Lima	14♂	45.0 (40.0-49.0)
2				20♂	46.0 (43.5-50.0)
3				15♀	39.8 (26.0-41.0)
4	1524	U.S.	Denver	40♂	48.4 (43.8-53.6)
5				40♀	43.2 (37.1-46.1)
6	1830-1890	India	Coonoor and Wellington	80♂	49.0 (38.0-65.0)
7	2300	India	Ootacamumd	20♂	49.4 (46.0-53.0)
8		Mexico	Mexico City	23♂' 21♀'	43.0 (37.5-49.0)
9				100♂	51.2 (45.0-58.5)
10				100♀	45.5 (41.5-50.0)
11	3730	Peru	Oroya	40♂	54.1 (47.8-65.4)
12	4540	Argentina	Mina Aguilar	81	59.5 (50.5-73.6)
13		Peru	Morococha	32	59.9 (48.7-71.1)
14				11	57.0 (46.0-71.0)

(') ages 4-6

	Altitude m	Country	Place	No. of subjects	Hematocrit ml RBC/100 ml blood
	1900	U.S.	South Lake Tahoe	8♀"	43.9 (39.5-49.5)

(") ages 12-14

Table X

TOTAL HEMATOCRIT FOR TRIALS TABLE

	T1	T2	T3	T4
Alt.	361	341	344.5	352.5
S.L.	343.5	350	358.5	361
	704.5	691	703.0	713.5

---

16 P. Altman, *Blood and Other Body Fluids*, Federation of American Societies for Experimental Biology, 1961, p. 192.

not a great deal can be conclusively commented. The main thing noted and already mentioned was the superior performances on the warmest testing day.

Chapter 5

SUMMARY AND CONCLUSIONS

In order to resolve the problem of whether or not middle altitude dwelling girls experience performance impairment at sea level, eight females--interested in track and living at medium altitude--were selected for this experiment. These girls, 12, 13, 14 years of age, participated in eight treatment sessions. Four sessions were at an altitude of 6,256 feet and four were at approximately sea level. At each treatment session all subjects had a fingertip blood sample taken for a hematocrit reading. At each treatment session all subjects participated separately and without competition in a 50 yard dash, 440 yard dash, softball throw, and 880 yard run. These events were to represent the assortment found at a track meet. Recordings were made of the temperature, humidity, barometric pressure and air pollution. Also, notes were taken concerning physical complaints of the subjects and winds.

The 880 and softball throw demonstrated the effects of training and learning over the eight weeks of testing. The 50 yard dash was the only event with a significant altitude effect. And, surprisingly, superior performances were made at sea level. A combination of factors caused this reversal from the findings in previous investigations.

1. The 50 yard dash was the first event each day, and so most reflecting the quality of the warm-up.

2. A beautiful warm day on the first sea level test aided performance.
3. High barometric readings at altitude left less of a pressure difference with sea level than expected.
4. At the altitude track the subjects usually ran into the wind while they ran with it at sea level.

Although, no altitude significance at the five percent level of significance was found for the 440, 880, and softball throw; the 440 was run faster at altitude, and the 880 was faster at sea level. About all that can be said about the softball throw at the two levels, is that the throws were more consistent at altitude in a linear trend toward improvement.

Except for the 50 yard dash, the results fell fairly close to the predictions which were: 1) Improvement would be noted over the eight weeks of testing due to training and learning. 2) The softball throw, 50 yard dash, and 440 yard run would be impaired at sea level. 3) The 880 yard run on the first sea level test would be on a par or better than the average of the altitude test, but would be impaired if there was hot weather toward summer. There was no hot weather in May, so performances continued to be better.

Although little statistically conclusive has been said about any of the variables investigated, some important conclusions can be made.

First, the altitude factor of reduced air pressure does not stand alone, but is accompanied by its relative climatic conditions. The difference in partial pressure was of borderline importance and to young female athletes posed no particular problems specific to them. Decided gains were made, training and learning may have exceeded what would have occurred with training at only one altitude. The hematocrit readings were in the upper normal ranges related to sea level norms and were similar to readings obtained from women residing at similar altitudes. They did fluctuate randomly from test to test which is normally due to daily changes in the amount of activity and/or absorption of water or dehydration.

To the coach these conclusions warrant saying that healthy, young female athletes from middle altitude should be able to compete at various altitudes if proper care is given to getting adequate rest. Unusual care should be made in dosing warm-ups appropriate to conditions, and the activity to follow. Attention should be given to insuring adequate fluid intake also. The young human body has a marvelous facility for meeting and dealing with change.

Despite the intensive work which has been done in altitude physiology, there are still questions regarding sea level performance by athletes dwelling and training at altitude. These questions center around the hypersensitive respiratory response of these individuals and resultant pH changes in the blood. Additional insight into ventilation, O_2 debt, and blood lactate levels by the collection of energy metabolism data, including blood acid-base parameters, during and after running events would add considerably to the body of knowledge in this area.

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APPENDIX

Statistical Treatments

HEMATOCRIT

% Volume

Altitude

S_1					
S_2	2162.25 46.5	1764 42	1764 42	2352.25 48.5	
S_3					
S_4	2070.25 45.5	1936 44	1892.25 43.5	1936 44	
S_5	1892.50 43.5	1681 41	2070.25 45.5	1936 44	
S_6	1849 43	1600 40	1849 43	1849 43	
S_7	2450.25 49.5	2401 49	2025 45	1849 43	
S_8	1849 43	1681 41	1640.25 40.5	1806.25 42.5	
S_9	2025 45	1806.25 42.5	1806.25 42.5	1892.50 43.5	
S_{10}	2025 45	1722.25 41.5	1806.25 42.5	1936 44	
$\Sigma\chi$	361 1	341 3	344.5 6	352.5 8	Σ 1399 $(\Sigma\chi)^2$ Alt. 1957201
$(\Sigma\chi)^2$	130321	116281	118680.25	124256.25	
$\Sigma\chi^2$	16323.25	14591.50	14853.25	15557	

HEMATOCRIT

% Volume

Sea Level

S_1				
S_2	2401 49	2116 46	2401 49	2209 47
S_3				
S_4	1640.25 40.5	1892.25 43.5	1936 44	1980.25 44.5
S_5	1849 43	1806.25 42.5	1681 41	1892.25 43.5
S_6	1560.25 39.5	1681 41	1936 44	1849 43
S_7	2070.25 45.5	2256.25 47.5	2256.25 47.5	2256.25 47.5
S_8	1600 40	1600 40	1806.25 42.5	1849 43
S_9	2116 46	1806.25 42.5	2209 47	2025 45
S_{10}	1600 40	2209 47	1892.25 43.5	2256.25 47.5
$\Sigma\chi$	343.5 2	350 4	358.5 5	361 7
$(\Sigma\chi)^2$	117992.25	122500	128522.25	130321
$\Sigma\chi^2$	14836.75	15367	16117.75	16316.75

HEMATOCRIT (Continued)

	$\Sigma\chi$	$(\Sigma\chi)^2$	$\Sigma\chi^2$
S_1			
S_2	370	136900	17169.50
S_3			
S_4	349.5	122150.25	15283.25
S_5	344	118336	14808.25
S_6	336.5	113232	14173.25
S_7	374.5	140250.25	17564.25
S_8	332.5	110556.25	13831.75
S_9	354	125316	15686.25
S_{10}	351	123201	15447
$\Sigma\chi$	$\Sigma\chi$ 2812	Subjects $(\Sigma\chi)^2$ 989941.75	
$(\Sigma\chi)^2$	Σ 1413 $(\Sigma\chi)^2$ S.L. 1996569	$(\Sigma\chi)^2$ 7907344	
$\Sigma\chi^2$			$\Sigma\chi^2$

HEMATOCRIT

Subjects X Altitudes

S_2	32041 179	36481 191	68522 370
S_4	31329 177	29756.25 172.5	61085.25 349.5
S_5	30276 174	28900 170	59176 344
S_6	28561 169	28056.25 167.5	56617.25 336.5
S_7	34782.25 186.5	35344 188	70126.25 374.5
S_8	27889 167	27390.25 165.5	55279.25 332.5
S_9	30102.25 173.5	32580.25 180.5	62682.5 354
S_{10}	29929 173	31684 178	61613 351
	244909.5	250192	495101.5

$$\frac{495101.5}{4} - \frac{(\Sigma\chi)^2}{64} = 123775.375 - 123552.25 = 223.125$$

HEMATOCRIT

Sub X Trials

	T1	T2	T3	T4	
S_1					
S_2	9120.25 95.5	7744 88	8281 91	9120.25 95.5	34265.5
S_3					
S_4	7396 86	7656.25 87.5	7656.25 87.5	7832.25 88.5	30540.75
S_5	7482.25 86.5	6972.25 83.5	7482.25 86.5	7656.25 87.5	29593
S_6	6806.25 82.5	6561 81	7569 87	7396 86	28332.25
S_7	9025 95	9312.25 96.5	8556.25 92.5	8190.25 90.5	35083.75
S_8	6889 83	6561 81	6889 83	7310.25 85.5	27649.25
S_9	8281 91	7225 85	8010.25 89.5	7832.25 88.5	31348.50
S_{10}	7225 85	7832.25 88.5	7396 86	8372.25 91.5	30825.50
	$\Sigma\chi^2$ 62224.75	59864	61840	63709.75	247638.5

$$\frac{247638.5}{2} - 123552.25 = 123819.25 - 123552.25 = 267$$

SS Subjects = 190.4675

$$\frac{136900}{8} + \frac{122150.25}{8} + \frac{118336}{8} + \frac{113232}{8} + \frac{140250.25}{8} +$$

$$\frac{110556.25}{8} + \frac{125316}{8} + \frac{123201}{8} - \frac{7907344}{64}$$

123742.7175 - 123552.25 = 190.4675

SS Altitude = 3.075

$$\frac{1957201}{32} + \frac{1996569}{32} - \frac{7907344}{64} = 123555.325 - 123552.25 =$$

3.075

HEMATOCRIT (Continued)

SS trials = 16.0312

$$\frac{496320.25}{16} + \frac{477481}{16} + \frac{494209}{16} + \frac{509082.25}{16} - 123552.25$$

12356.82812 - 123552.25 = 16.0312

SS treatments = 57

$$\frac{130321}{8} + \frac{116281}{8} + \frac{118680.25}{8} + \frac{124256.25}{8} + \frac{117992.25}{8} + \frac{122500}{8} +$$

$$\frac{128522.25}{8} + \frac{130321}{8} - \frac{7907344}{64}$$

123609.25 - 123552.25 = 57

SS trials x alt. = SS treatments - SS trials - SS alt = 37.8929

57 - 16.0312 = 3.075 = 37.8929

SS error = 163.7825

411.25 - 190.4675 - 57 = 163.7825
total subjects treatments

SS total = 411.25

$$\Sigma\chi^2 - \frac{(\Sigma\chi)^2}{64} \quad 123963.5 - 123552.25 = 411.25$$

Sub X trials = $SS_{total} - SS_s$ - SS trials

267 - 190.4675 - 16.0312 = 60.5013

Sub X Alt = SS total - SS_s - SS Alt

223.125 - 190.4675 - 3.075 = 29.5825

SS_s X trials X Alt = SS error - $SS_{s\ x\ Trials}$ - $SS_{s\ x\ alt}$.

163.7825 - 60.5013 - 29.5825 = 73.6987

Table VIII

HEMATOCRIT ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	190.46	7	27.21		
Treatments	57	7	8.14		
trials	16.03	3	5.34	1.85	no
altitude	3.07	1	3.07	0.73	no
alt x trials	37.89	3	12.63	3.60	sig. 5%
Error	163.78	49	3.34		
sub x alt	29.58	7	4.22		
sub x trials	60.50	21	2.88		
sub x alt x trials	73.69	21	3.50		
Total	411.25	63	6.52		

F .05 2.21
.01 (7,49) 3.03

F .05 3.07
.01 (3,21) 4.87

F .05 4.32
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

SOFTBALL THROW

	Altitude				
S_2	5625	4096	4489	4692.25	
	75	64	67	68.5	
S_4	5929	6084	6889	7744	
	77	78	83	88	
S_5	4096	4096	3364	2916	
	64	64	58	54	
S_6	5329	6400	7744	9604	
	73	80	88	98	
S_7	5929	6241	7482.25	7921	
	77	79	86.5	89	
S_8	4356	5329	7744	6724	
	66	73	88	82	
S_9	16900	16900	17556.25	18769	
	130	130	132.5	137	
S_{10}	8281	12100	12769	14884	
	91	110	113	122	
$\Sigma\chi$	653	678	716	738.5	Σ 2785.5
	1	3	6	8	$(\Sigma\chi)^2$ alt 7759010.25
$(\Sigma\chi)^2$	426409	459684	512656	545382.25	
$\Sigma\chi^2$	56445	61246	68037.5	73254.25	

SOFTBALL THROW

Sea Level

S_2	4489 67	3721 61	4761 69	6084 78
S_4	7225 85	7225 85	6561 81	6889 83
S_5	3025 55	3025 55	2916 54	2601 51
S_6	6724 82	7921 89	4761 69	9401 97
S_7	7921 89	6889 83	4624 68	6724 82
S_8	5041 71	6724 82	6241 79	6561 81
S_9	16641 129	17424 132	15625 125	14161 119
S_{10}	10816 104	14161 119	11449 107	11025 105
$\Sigma\chi$	682 2	706 4	652 5	696 7
$(\Sigma\chi)^2$	465124	498436	425104	484416
$\Sigma\chi^2$	61882	67090	56938	63446

SOFTBALL THROW

	$\Sigma\chi$	$(\Sigma\chi)^2$	$\Sigma\chi^2$
S_2	549.5	301950.25	37957.25
S_4	660	435600	54546
S_5	455	207025	26039
S_6	676	456976	57884
S_7	653.5	427062.25	53731.25
S_8	622	386884	48720
S_9	1034.5	1070190.25	133976.25
S_{10}	871	758641	95485
$\Sigma\chi$	$\Sigma\chi$ 5521.5		
$(\Sigma\chi)^2$		Σ 2736 $(\Sigma\chi)^2$ S.L. 7485696	
$\Sigma\chi^2$			$\Sigma\chi^2$ 508338.75

SOFTBALL THROW

Subject X Trials

	T1	T2	T3	T4	
S_1					
S_2	20164 142	15625 125	18496 136	21462.25 146.5	75747.25 549.5
S_3					
S_4	26244 162	26569 163	26896 164	29241 171	108950 660
S_5	14161 119	14161 119	12544 112	11025 105	51891 455
S_6	24025 155	28561 169	24649 157	38025 195	115260 676
S_7	27556 166	26244 162	23870.25 154.5	29241 171	106911.25 653.5
S_8	18769 137	24025 155	27889 167	26569 163	97252 622
S_9	67081 259	68644 262	66306.25 257.5	65536 256	267567.25 1034.5
S_{10}	38025 195	52441 229	48400 220	51529 227	190395 871
	236025	256270	249050.5	272628.25	1013973.75

$$\frac{1013973.75}{2} - (\Sigma\chi)^2 = 506986.875 - 476358.7851 = 30628.0899$$

SOFTBALL THROW

Subjects X Altitudes

	Alt	S.L.	$\Sigma\chi$
S_2	75350.25 274.5	75625 275	150975.25 549.5
S_4	106276 326	111556 334	217832 660
S_5	57600 240	46225 215	103825 455
S_6	114921 339	113569 337	228490 676
S_7	109892.25 331.5	103684 322	213576.25 653.5
S_8	95481 309	97969 313	193450 622
S_9	280370.25 529.5	255025 505	535395.25 1034.5
S_{10}	190096 436	189225 435	379321 871
	1029986.75	992878	2022864.75

$$\frac{2022864.75}{4} - \frac{(\Sigma\chi)^2}{64} = \text{total}$$

505716.1875 - 476358.7851 = 29357.4024

SS Subjects = 29182.3086

$$\frac{301950.25}{8} + \frac{435600}{8} + \frac{207025}{8} + \frac{456976}{8} + \frac{427062.25}{8} + \frac{386884}{8} +$$

$$\frac{1070190.25}{8} + \frac{758641}{8} - \frac{30486962.25}{64}$$

505541.0937 - 476358.7851 = 29182.3086

SS treatments = 792.6211

$$\frac{426409}{8} + \frac{459684}{8} + \frac{512656}{8} + \frac{545382.25}{8} + \frac{465124}{8} + \frac{498436}{8} +$$

$$\frac{425104}{8} + \frac{484416}{8} - 476358.7851$$

477151.4062 - 476358.7851 = 792.6211

SOFTBALL THROW (Continued)

SS trials = <u>322.168</u>

$$\frac{1782225}{16} + \frac{1915456}{16} + \frac{1871424}{16} + \frac{2057790.25}{16} - 476358.7851$$

476680.9531 - 476358.7851 = 322.168

SS Altitude = <u>38.2849</u>

$$\frac{7759010.25}{32} + \frac{7485696}{32} - 476358.7851$$

476397.07 - 476358.7851 = 38.2849

SS Alt. X Trials = <u>432.1682</u>

792.6211 - 322.168 - 38.2849 = 432.1682
treatments trials altitude

SS total = 31979.9649

508338.75 - 476358.7851 = 31979.9649

sub x trials = <u>1123.6133</u>

30628.0899 - 29182.3086 - 322.168 = 1123.6133
SS total $-SS_{sub}$ $- SS_{trials}$

Sub X Alt = 136.8089

29357.4024 - 29182.3086 - 38.2849 = <u>136.8089</u>
SS total $-SS_{sub}$ $-SS_{alt}$

sub X trials X alt = <u>744.613</u>

2005.0352 - 1123.6133 - 136.8089 = <u>744.613</u>
SS error - SS_{sub} x Trials $- SS_{sub\ x\ alt}$

Table VI

SOFTBALL THROW ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	29182.31	7	4168.90		
Treatments	792.62	7	113.23		
altitude	38.28	1	38.28	1.96	no
trials	322.17	3	107.38	2.01	no
trials x alt.	432.16	3	144.056	4.06	sig. 58
Error	2005.03	49	40.92		
sub x alt	136.81	7	19.54		
sub x trials	1123.61	21	53.50		
sub x trials x alt.	744.61	21	35.45		
Total	31979.96	63	507.61		

F .05 2.21
.01 (7,49) 3.03

F .05 3.07
.01 (3,21) 4.87

F .05 4.32
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

50 YD. DASH

	Altitude				
S_2	59.29 7.7	60.84 7.8	56.25 7.5	60.84 7.8	
S_4	53.29 7.3	60.84 7.8	64.00 8.0	59.29 7.7	
S_5	67.24 8.2	67.24 8.2	59.29 7.7	62.41 7.9	
S_6	47.61 6.9	47.61 6.9	44.89 6.7	49.00 7.0	
S_7	57.76 7.6	57.76 7.6	62.41 7.9	60.84 7.8	
S_8	56.25 7.5	60.84 7.8	62.41 7.9	54.76 7.4	
S_9	51.84 7.2	51.84 7.2	50.41 7.1	50.41 7.1	
S_{10}	51.84 7.2	51.84 7.2	47.61 6.9	49.00 7.0	
$\Sigma\chi$	59.60 1	60.50 3	59.70 6	59.70 8	Σ 239.5 $(\Sigma\chi)^2$ Alt 57360.25
$(\Sigma\chi)^2$	3552.16	3660.25	3564.09	3564.09	
$\Sigma\chi^2$	445.12	458.81	447.27	446.55	

50 YD. DASH

Sea Level

S_2	54.76 7.4	51.84 7.2	56.25 7.5	56.25 7.5
S_4	54.76 7.4	56.25 7.5	54.76 7.4	57.76 7.6
S_5	60.84 7.8	59.29 7.7	64.00 8.0	62.41 7.9
S_6	42.25 6.5	46.24 6.8	42.25 6.5	46.24 6.8
S_7	57.76 7.6	57.76 7.6	57.76 7.6	59.29 7.7
S_8	53.29 7.3	57.76 7.6	56.25 7.5	56.25 7.5
S_9	47.61 6.9	50.41 7.1	49.00 7.0	51.84 7.2
S_{10}	50.41 7.1	47.61 6.9	46.24 6.8	42.25 6.5
$\Sigma\chi$	58.00 2	58.40 4	58.30 5	58.70 7
$(\Sigma\chi)^2$	3364	3410.56	3398.89	3445.69
$\Sigma\chi^2$	421.68	427.16	426.51	432.29

50 YD. DASH

	$\Sigma\chi$	$(\Sigma\chi)^2$	$\Sigma\chi^2$
S_2	60.4	3648.16	456.32
S_4	60.7	3684.49	460.95
S_5	63.4	4019.56	502.72
S_6	54.1	2926.81	366.09
S_7	61.4	3769.96	471.34
S_8	60.5	3660.25	457.81
S_9	56.8	3226.24	403.36
S_{10}	55.6	3091.36	386.80
$\Sigma\chi$	$\Sigma\chi$ 472.9		
$(\Sigma\chi)^2$		$\Sigma\chi$ S.L. 2334 $(\Sigma\chi)^2$ 54475.56	
$\Sigma\chi^2$			$\Sigma\chi^2$ 3505.39

50 YD. DASH

Subject X Trials

	T1	T2	T3	T4	
S_2	228.01	225	225	234.09	912.1
	15.1	15.0	15.0	15.3	60.4
S_4	216.09	234.09	237.16	234.09	921.43
	14.7	15.3	15.4	15.3	60.7
S_5	256.0	252.81	246.49	249.64	1004.94
	16.0	15.9	15.7	15.8	63.4
S_6	179.56	187.69	174.24	190.44	731.93
	13.4	13.7	13.2	13.8	54.1
S_7	231.04	231.04	240.25	240.25	942.58
	15.2	15.2	15.5	15.5	61.4
S_8	219.04	237.16	237.16	222.01	915.37
	14.8	15.4	15.4	14.9	60.5
S_9	198.81	204.49	198.81	204.49	806.6
	14.1	14.3	14.1	14.3	56.8
S_{10}	204.49	198.81	187.69	182.25	773.24
	14.3	14.1	13.7	13.5	55.6
	1733.04	1771.09	1746.8	1757.26	7008.19

$$\frac{7008.19}{2} - \frac{(\Sigma\chi)^2}{64} = \text{total}$$

$$3504.095 - 3494.2876562 = 9.807763$$

50 YD. DASH

Subjects X Altitudes

	Alt.	S.L.	Σ
S_2	948.64 30.8	876.16 29.6	1824.8 60.4
S_4	948.64 30.8	894.01 29.9	1842.65 60.7
S_5	1024. 32	985.96 31.4	2009.96 63.4
S_6	756.25 27.5	707.56 26.6	1463.81 54.1
S_7	954.81 30.9	930.25 30.5	1885.06 61.4
S_8	936.36 30.6	894.01 29.9	1830.37 60.5
S_9	817.96 28.6	795.24 28.2	1613.2 56.8
S_{10}	800.89 28.3	745.29 27.3	1546.18 55.6
	7187.55	6828.48	14016.03

$$\frac{14016.03}{4} - (\Sigma\chi)^2 = 3504.0075 - 3494.2876562 = 9.719844$$

total

SS subjects = 9.066094

$$\frac{3648.16}{8} + \frac{3684.49}{8} + \frac{4019.56}{8} + \frac{2926.81}{8} + \frac{3769.96}{8} + \frac{3660.25}{8} +$$

$$\frac{3226.40}{8} + \frac{3091.36}{8} - \frac{223634.41}{64}$$

3503.35375 - 3494.2876562 = 9.066094

SS treatments = .6785938

$$\frac{3552.16}{8} + \frac{3600.25}{8} + \frac{3564.09}{8} + \frac{3564.09}{8} + \frac{3364}{8} + \frac{3410.56}{8} +$$

$$\frac{3398.89}{8} - \frac{223634.41}{64}$$

3494.96625 - 3494.2876562 = .6785938

50 YD. DASH (Continued)

SS trials = .581406

$$\frac{13829.76}{16} + \frac{14137.21}{16} + \frac{13924}{16} + \frac{14018.56}{16} - 3494.2876562 =$$

3494.345625 - 3494.2876562 = .581406

SS Alt X trials = .0392090

.6785938 - .0579788 - .581406 = .039209
treatments - trials - alt

SS Altitude = .581406

$$\frac{57360.25}{32} + \frac{54475.56}{32} - \frac{223634.41}{64}$$

3494.869062 - 3494.2876562 = .581406

SS Error = 1.3576562

11.102344 - 9.066094 - .6785938 = 1.3576562
total - subjects - treatments

SS total = 11.102344 $\Sigma\chi^2 - \frac{(\Sigma\chi)^2}{N}$

3505.39 - 3494.287656 = 11.102344

$SS_{sub\ x\ trials}$ = 9.807763 - 9.066094 - .581406 = .160263
SS_{total} $-SS_{sub}$ $-SS_{trials}$

$SS_{sub\ x\ Alt}$ = .5957712

9.719844 - 9.066094 - .0579788 = .5957712
SS_{total} SS_{sub} SS Alt.

$SS_{sub\ x\ trials\ X\ Alt}$

1.3576562 - .160263 - .5957712 = .601622
SS_{error} $-SS_{sub\ X\ trials}$ $-SS_{sub\ X\ Alt}$

Table V

50 YARD DASH ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	9.06	7	1.29		
Treatments	.68	7	.09		
trials	.06	3	.01	2.53	no
altitude	.58	1	.58	6.83	sig. 5%
alt. x trials	.039	3	.013	0.46	no
Error	1.36	49	.027		
sub x alt	.59	7	.085		
sub x trials	.16	21	.007		
sub x trials x alt.	.60	21	.028		
Total	11.10	63	.18		

F .05 2.21
.01 (7,49) 3.03

F .05 3.07
.01 (3,21) 4.87

F .05 4.34
.01 (1,21) 8.02

F .05 5.59
.01 (1,7) 12.25

880 YD. RUN

	Altitude				
S_2	37597.21 193.9	34447.36 185.6	33379.29 182.7	32616.36 180.6	
S_4	50850.25 225.5	50805.16 225.4	47961 219	41209 203	
S_5	61951.21 248.9	49729 223	59000.41 242.9	52441 229	
S_6	35268.84 187.8	34410.25 185.5	32292.09 179.7	38769.61 196.9	
S_7	56453.76 237.6	55648.81 235.9	43681 209	44100 210	
S_8	57456.09 239.7	50131.21 223.9	46483.36 215.6	46483.36 215.6	
S_9	47742.25 218.5	37908.09 194.7	41534.44 203.8	39601 199	
S_{10}	45369 213	37869.16 194.6	36442.41 190.9	34521.64 185.8	
$\Sigma\chi$	1764.9 1	1668.6 3	1643 6	1619.9 8	$\Sigma\chi$ 6697 $(\Sigma\chi)^2$ alt 44849809
$(\Sigma\chi)^2$	3114872.01	2784225.96	2701420.96	2624076.01	
$\Sigma\chi^2$	392688.61	350949.04	340774	329741.97	

880 YD. RUN

Sea Level

S_2	34373.16	37403.56	32797.21	34894.24
	185.4	193.4	181.1	186.8
S_4	43388.89	50625	46139.04	40561.96
	208.3	225	214.8	201.4
S_5	50625	56169	50086.44	49773.61
	225	237	223.8	223.1
S_6	32112.64	34856.89	30940.81	33051.24
	179.2	186.7	175.9	181.8
S_7	51574.41	52120.89	50760.09	48929.44
	227.1	228.3	225.3	221.2
S_8	46268.01	60762.25	51483.61	40561.96
	215.1	246.5	226.9	201.4
S_9	38064.01	37713.64	35231.29	36252.16
	195.1	194.2	187.7	190.4
S_{10}	45753.21	38927.29	40000	36062.01
	213.9	197.3	200	189.9
$\Sigma\chi$	1649.1	1708.4	1635.5	1596
	2	4	5	7
$(\Sigma\chi)^2$	2719530.81	2918630.56	2674860.25	2547216.
$\Sigma\chi^2$	342159.33	368578.52	337438.49	320086.62

880 YD. RUN

	$\Sigma\chi$	$(\Sigma\chi)^2$	$\Sigma\chi^2$
S_2	1489.5	2218610.25	277508.39
S_4	1722.4	2966661.76	371540.30
S_5	1852.7	3432497.29	429775.67
S_6	1473.5	2171202.25	271702.37
S_7	1794.4	3219871.36	403268.40
S_8	1784.7	3185154.09	399629.85
S_9	1583.4	2507155.56	314046.88
S_{10}	1585.4	2513493.16	314944.72
$\Sigma\chi$	$\Sigma\chi$ 13286		
$(\Sigma\chi)^2$	$(\Sigma\chi)^2$ 17517796	$\Sigma\chi$ S.L. 6589 $(\Sigma\chi)^2$ 43414921	
$\Sigma\chi^2$			$\Sigma\chi^2$ 2782416.58

880 YD. RUN

Subject X Trials

S_2	143868.49 379.3	143641 379	132350.44 363.8	134982.76 367.4	554842.69 1489.5
S_4	188182.44 433.8	202860.16 450.4	188182.44 433.8	163539.36 404.4	742764.4 1722.4
S_5	224581.21 473.9	211600 460	217808.89 466.7	204394.41 452.1	858384.51 1852.7
S_6	134689. 367	138532.84 372.2	126451.36 355.6	143413.69 378.7	543086.89 1473.5
S_7	215946.09 464.7	215481.64 464.2	188616.49 434.3	185933.44 431.2	805977.66 1794.4
S_8	206843.04 454.8	221276.16 470.4	195806.25 442.5	173889 417	797814.45 1784.7
S_9	171064.96 413.6	151243.21 388.9	153272.25 391.5	151632.36 389.4	627212.78 1583.4
S_{10}	182243.61 426.9	153585.61 391.9	152802.81 390.9	141150.49 375.7	629782.52 1585.4
	1467418.84	1438220.62	1355290.93	1298935.51	5559865.9

$$\frac{5559865.9}{2} - 2758090.5 =$$

2779932.95 - 2758090.5 = 21842.45 total

Trials Table

	T1	T2	T3	T4
Alt	1764.9 1	1668.6 3	1643.6 6	1619.9 8
S.L.	1649.1 2	1708.4 4	1635.5 5	1596 7
	3414	3377	3279.1	3215.9
	11655396	11404129	10752496.81	10342012.81

$$\frac{44154034.62}{16} - 2758090.5$$

$$2759627.163 - 2758090.5 = 1536.663$$

880 YD RUN

Sub X Alt

	Alt	S.L.	Σ
S_2	551751.84 742.8	557560.89 746.7	1109312.73 1489.5
S_4	761954.41 872.9	721650.25 849.5	1483604.66 1722.4
S_5	890758.44 943.8	826099.21 908.9	1716857.65 1852.7
S_6	562350.01 749.9	523596.96 723.6	1085946.97 1473.5
S_7	796556.25 892.5	813426.61 901.9	1609979.86 1794.4
S_8	800667.04 894.8	791922.01 889.9	1592589.05 1784.7
S_9	665856 816	588902.76 767.4	1254758.76 1583.4
S_{10}	615126.49 784.3	641761.21 801.1	1256887.7 1585.4
	5645020.48	5464916.9	11109937.38

$$\frac{11109937.38}{4} - 2758090.5$$

$$2777484.34 - 2758090.5 = 19393.84$$

880 YD. RUN (Continued)

SS Subjects = $\underline{18740.21}$

$$\frac{2218610.25}{8} + \frac{2966661.76}{8} + \frac{3433979.61}{8} + \frac{2171202.25}{8} + \frac{3219871.36}{8} +$$

$$\frac{3185154.09}{8} + \frac{2507155.56}{8} + \frac{2513493.16}{8} - \frac{(13286)^2}{64}$$

$$\frac{2221465.72}{8} - \frac{176517796}{64} = 2776830.71 - 2758090.5 = \underline{18740.21}$$

SS treatments = $\underline{2513.57}$

$$\frac{3114872.01}{8} + \frac{2784225.96}{8} + \frac{2701420.96}{8} + \frac{2624076.01}{8} + \frac{2719530.81}{8} +$$

$$\frac{2918630.56}{8} + \frac{2674860.25}{8} + \frac{2547216.0}{8} - 2758090.5$$

$$\frac{22084832.56}{8} - 2758090.5 = 2760604.07 - 2758090.5 = \underline{2513.57}$$

SS trials = $\underline{1536.663}$

$$\frac{44154034.62}{16} - 2758090.5 = 2759627.163 - 2758090.5 = \underline{1536.663}$$

SS Altitude = $\underline{182.3}$

$$\frac{44849809}{32} + \frac{43414921}{32} - 2758090.5 = 2758272.8 - 2758090.5 = \underline{182.3}$$

SS Alt X Trials = $\underline{794.607}$

2513.57 - 1536.663 - 182.3 = $\underline{794.607}$
treatments - trials - altitude

SS Error =

24326.08 - 18740.21 - 2513.57 = 3072.3
total - subjects - treatments

$$\text{SS total} = \Sigma\chi^2 - \frac{(\Sigma\chi)^2}{N}$$

2782416.58 - 2758090.5 = $\underline{24326.08}$

$SS_{\text{sub X Alt}} = \underline{471.33}$

19393.84 - 18740.21 - 182.3 = $\underline{471.33}$
total $-SS_{sub}$ $-SS_{Alt}$

880 YD. RUN (Continued)

$SS_{sub\ X\ trial}$ = <u>1565.577</u>

21842.45 - 18740.21 - 1536.663 = <u>1565.577</u>
total - SS_{sub} - SS_{trials}

$SS_{Sub\ X\ Trials\ X\ Alt}$ = <u>1035.393</u>

3072.3 - 1565.577 - 471.33 = <u>1035.393</u>
error - $SS_{Sub\ X\ Trials}$ - $SS_{Sub\ X\ Alt}$

ONLY SIGNIFICANT TRIALS EFFECT

Linear Trend Analysis

880 yd. run

SS trials 1536.663

SS linear 1497.3151

$$\frac{[\overset{A_1}{(-3)}\,\overset{t_1}{3414} + \overset{A_2}{(-1)}\,\overset{t_2}{3377} + \overset{A_3}{(1)}\,\overset{t_3}{3279.1} + \overset{A_4}{(3)}\,\overset{t_4}{3215.9}]^2}{\underset{n\ \Sigma A_1{}^2}{16(20)}}$$

$$\frac{[(-10242) + (-3377) + 3279.1 + 9647.7]^2}{320}$$

$$\frac{[(-13619) + 12926.8]^2}{320} = \frac{(692.2)^2}{320} = \frac{479140.84}{320} = 1497.3151$$

Table III

880 YARD RUN ANOVA TABLE

Source	SS	d.f.	ms	F	p
Subjects	18740.21	7	2677.17		
Treatments	2513.57	7	359.08	5.72	sig. 1%
trials	1536.66	3	512.22	6.87	sig. 1%
linear	1497.31	1	1497.31	20.08	sig. 1%
altitude	182.3	1	182.3	2.71	no sig.
trials x alt.	794.60	3	264.87	5.37	sig. 1%
Error	3072.3	49	62.7		
sub x alt	471.33	7	67.33		
sub x trials	1565.57	21	74.55		
sub x trials x alt	1035.39	21	49.30		
Total	24326.08	63	3861.44		

F .05 4.04
.01 (1,49) 7.18

F .05 4.32
.01 (1,21) 8.02

F .05 3.07
.01 (3,21) 4.87

F .05 5.59
.01 (1,7) 12.25

440 YD. DASH

Altitude

S_2	6938.89 83.3	5821.69 76.3	6177.96 78.6	5836.96 76.4	
S_4	7921 89	8226.49 90.7	8760.96 93.6	7242.01 85.1	
S_5	9940 99.7	8704.89 93.3	9840.64 99.2	9196.81 95.9	
S_6	6068.41 77.9	5640.01 75.1	6642.25 81.5	6464.16 80.4	
S_7	8930.25 94.5	7832.25 88.5	10020.01 100.1	7673.76 87.6	
S_8	10404 102	8281 91	9940.09 99.7	6872.41 82.9	
S_9	7089.64 84.2	6416 80.1	6577.21 81.1	6496.36 80.6	
S_{10}	7039.21 83.9	6115.24 78.2	6256.81 79.1	5655.04 75.2	
$\Sigma\chi$	714.5 1	673.2 3	712.9 6	664.1 8	Σ 2764.7 $(\Sigma\chi)^2$ Alt 7643566.09
$(\Sigma\chi)^2$	510510.25	453198.24	508226.41	441028.81	
$\Sigma\chi^2$	64331.4	57037.57	64215.93	55437.51	

440 YD. DASH

Sea Level

S_2	6625.96	6691.24	6674.89	6512.49
	81.4	81.8	81.7	80.7
S_4	7796.89	8226.49	8742.25	7638.76
	88.3	90.7	93.5	87.4
S_5	9820.81	10629.61	10836.81	11257.21
	99.1	103.1	104.1	106.1
S_6	5595.04	6162.25	6006.25	7761.61
	74.8	78.5	77.5	88.1
S_7	7191.04	8704.89	9101.16	8046.09
	84.8	93.3	95.4	89.7
S_8	8537.76	8873.64	10060.09	7621.29
	92.4	94.2	100.3	87.3
S_9	6593.44	7140.25	6496.36	7039.21
	81.2	84.5	80.6	83.9
S_{10}	7276.09	6336.16	6707.61	6146.56
	85.3	79.6	81.9	78.4
$\Sigma\chi$	687.3	705.7	715	701.6
	2	4	5	7
$(\Sigma\chi)^2$	472381.29	498012.49	511225	492242.56
$\Sigma\chi^2$	59437.03	62764.53	64625.42	62023.22

440 YD. DASH

	$\Sigma\chi$	$(\Sigma\chi)^2$	$\Sigma\chi^2$
S_2	640.2	409856.04	51280.08
S_4	718.3	515954.89	64554.85
S_5	800.5	640800.25	80226.78
S_6	633.8	401702.44	50339.98
S_7	733.9	538609.21	67499.45
S_8	749.8	562200.04	70590.28
S_9	656.2	430598.44	53848.47
S_{10}	641.6	411650.56	51532.72
$\Sigma\chi$	$\Sigma\chi$ 5574.3		
$(\Sigma\chi)^2$		$\Sigma\chi$ S.L. 2809.6 $(\Sigma\chi)^2$ 7893852.16	
$\Sigma\chi^2$			$\Sigma\chi^2$ 489872.61

440 YD. DASH

Subject X Trials

	T1	T2	T3	T4	Σ
S_2	27126.09	24995.61	25696.09	24680.41	102498.2
	164.7	158.1	160.3	157.1	640.2
S_4	31435.29	32905.96	35006.41	29756.25	129103.91
	177.3	181.4	187.1	172.5	718.3
S_5	39521.44	38572.96	41330.89	40804	160229.29
	198.8	196.4	203.3	202	800.5
S_6	23317.29	23592.96	25281	28392.25	100583.5
	152.7	153.6	159	168.5	633.8
S_7	32148.49	33051.24	38220.25	31435.29	134855.27
	179.3	181.8	195.5	177.3	733.9
S_8	37791.36	34299.04	40000	28968.04	141058.44
	194.4	185.2	200	170.2	749.8
S_9	27357.16	27093.16	26146.89	27060.25	107657.46
	165.4	164.6	161.7	164.5	656.2
S_{10}	28628.64	24900.84	25921	23592.96	103043.44
	169.2	157.8	161	153.6	641.6
	247325.76	239411.77	257602.53	234689.45	97902951

$$\frac{979029.51}{2} - \frac{(\Sigma\chi)^2}{64} = \text{total } SS_{\text{sub x trials}}$$

$$489514.755 - 485512.8201 = 4001.9349 \text{ total}$$

440 YD. DASH

Trials Table

	T1	T2	T3	T4	
Alt	714.5	673.2	712.9	664.1	2764.7
S.L.	687.3	705.7	715	701.6	2809.6 5574.3
	1401.8	1378.9	1427.9	1365.7	

$$\frac{1965043.24}{16} + \frac{1901365.21}{16} + \frac{2038898.41}{16} +$$

$$\frac{1865136.49}{16} = \frac{7770443.35}{16} - \frac{(\Sigma X)^2}{64}$$

485652.7093 - 485512.8201 = 139.8892

Sub X Alt

	Alt	S.L.	
S_2	98973.16 314.6	106015.36 325.6	204988.52 640.2
S_4	128450.56 358.4	129528.01 359.9	257978.57 718.3
S_5	150621.61 388.1	170073.76 412.4	320695.37 800.5
S_6	99162.01 314.9	101697.21 318.9	200859.22 633.8
S_7	137418.49 370.7	131914.24 363.2	269332.73 733.9
S_8	141075.36 375.6	140025.64 374.2	281101. 749.8
S_9	106276 326	109032.04 330.2	215308.04 656.2
S_{10}	100108.96 316.4	105755.04 325.2	205864 641.6
	962086.15	994041.3	1956127.45

$$\frac{1956127.45}{4} - 485512.8201$$

489031.86 - 485512.8201 = 3519.0399

ONLY SIGNIFICANT TRIALS EFFECT

Linear Trend Analysis

440 yd. dash

SS trials = 139.8892

SS linear = 10.98903125

$$\frac{[\overset{A_1}{(-3)}\overset{t_1}{1401.8} + \overset{A_2}{(-1)}\ \overset{t_2}{1378.9} + \overset{A_3}{(1)}\overset{t_3}{1427.9} + \overset{A_4}{(3)}\overset{t_4}{1365.7}]^2}{\underset{n\ \Sigma A_1{}^2}{16(20)}}$$

$$\frac{[(-4205.4) + (-1378.9) + 1427.9 + 4097.1]^2}{320}$$

$$\frac{[(-5584.3) + 5525]^2}{320} = (-59.3)^2 = \frac{3516.49}{320} = 10.98903125$$

440 YARD DASH (Continued)

SS Subjects = 3408.6636

$$\frac{409856.04}{8} + \frac{515954.89}{8} + \frac{640800.25}{8} + \frac{401702.44}{8} + \frac{538609.21}{8} +$$

$$\frac{562200.04}{8} + \frac{430598.44}{8} + \frac{411650.56}{8} - \frac{(5574.3)^2}{64}$$

488921.4837 - 485512.8201 = 3408.6636

SS treatments = 340.311

$$\frac{510510.25}{8} + \frac{453198.24}{8} + \frac{508226.41}{8} + \frac{441028.8}{8} + \frac{472381.29}{8} +$$

$$\frac{498012.49}{8} + \frac{511225}{8} + \frac{492242.56}{8} - 485512.8201$$

485853.1312 - 485512.8201 = 340.3111

SS trials = 139.8892

$$\frac{196543.24}{16} + \frac{1901365.21}{16} + \frac{2038898.41}{16} + \frac{1865136.49}{16} - 485512.8201$$

485652.7093 - 485512.8201 = 139.8892

SS altitude = 31.5002

$$\frac{7643566.09}{32} + \frac{7893852.16}{32} - 485512.8201$$

485544.3203 - 485512.8201 = 31.5002

SS Trials X Alt = 168.9216

340.311 - 139.8892 - 31.5002 = 168.9216
SS treatments - SS trials - SS Alt

SS Error = 610.8152

4359.7899 - 3408.6636 - 340.3111 = 610.8152
total subjects treatments

SS total = 4359.7899

489872.61 - 485512.8201 = 4359.7899

$SS_{sub\ X\ alt}$ = 78.8761

3519.0399 - 3408.6636 - 31.5002 = 78.8761
SS total -SS sub - SS Alt

440 YARD DASH (Continued)

$SS_{sub\ X\ trials}$ = <u>453.3821</u>

4001.9349 - 3408.6636 - 139.8892 = <u>453.3821</u>
SS total $-SS_{sub}$ $-SS_{trials}$

$SS_{sub\ X\ trials\ X\ alt}$ =

610.8152 - 453.3821 - 78.8761 = 78.5570
error - sub X trials - sub X alt

Table IV

440 Yard Dash Anova Table

Source	SS	d.f.	ms	F	p
Subjects	3408.66	7	486.95		
Treatments	340.31	7	48.61		
trials	139.88	3	46.63	2.16	no
linear	10.98	1	10.98		
quad.	4.82	1	4.82		
cubic	104.76	1	104.76	4.80	sig. 5%
Altitude	31.50	1	31.50	2.79	no
Alt. x trials	168.92	3	56.30	15.06	sig. 1%
Error	610.81	49	12.46		
sub x alt	78.87	7	11.26		
sub x trials	453.38	21	21.59		
sub x trials x alt	78.55	21	3.74		
Total	4359.79	63	69.20		

F .05 4.04
.01 (1,49) 7.18

F .05 4.32
.01 (1,21) 8.02

F .05 3.07
.01 (3,21) 4.87

F .05 5.59
.01 (1,7) 12.25

CUBIC TREND ANALYSIS

SS Cubic 104.767531

$$\frac{[(-1)1401.8 + (3)1378.9 - 3(1427.9) + 1(1365.7)]^2}{16(20)} = \frac{(-183.1)^2}{320}$$

$$\frac{33525.61}{320} = 104.767537$$

QUADRATIC TREND ANALYSIS

SS quad = 4.826531

$$\frac{[(1)1401.8 - (1)1378.9 - 1(1427.9) + 1(1365.7)]^2}{16(20)} = \frac{(-39.3)^2}{320}$$

$$\frac{1544.49}{320} = 4.826531$$

Raw Scores

HEMATOCRITS

	Altitude				Sea Level			
	1	3	6	8	2	4	5	7
Subjects	4/8	4/21	5/13	5/27	4/15	4/28	5/6	5/20
Erin Kenney 2	46.5	42	42	48.5	49	46	49	47
Wendy McHalffey 4	45.5	44	43.5	44	40.5	43.5	44	44.5
Connie Smith 5	43.5	41	45.5	44	43	42.5	41	43.5
Danyll Ayrault 6	43	40	43	43	39.5	41	44	43
Marty Jeffries 7	49.5	49	45	43	45.5	47.5	47.5	47.5
Stacey Ayrault 8	43	41	40.5	42.5	40	40	42.5	43
Debbie Beach 9	45	42.5	42.5	43.5	46	42.5	47	45
Julie VanKleeck 10	45	41.5	42.5	44	40	47	43.5	47.5
Temp	51	54	64	66	82	72	60	66
Humidity	38/51 23%	42/54 23%	48/62 32%	56/66 53%	62/82 30%	54/72 28%	52/60 58%	56/66 53%
Bar.Press.	30.05	30.23	30.08	30.23	30.03	30.10	30.05	30.01
Air Pollution					30	26	19	14
	Clear Windy	Clear Slight Breeze	Breeze	Warm	Hot Still	Fair Breeze	Light fog High wind	Cloudy Windy

South Tahoe Airport — Hamilton Air Force Base

Subjects	Event	Altitude 4/8	Altitude 4/21	Altitude 5/13	Altitude 5/27	Sea Level 4/15	Sea Level 4/28	Sea Level 5/6	Sea Level 5/20
Danyll Ayrault 6	880	3:07.8	3:05.5	2:59.7	3:16.9	2:59.2	3:06.7	2:55.9	3:01.8
	440	1:17.9	1:15.1	1:21.5	1:20.4	1:14.8	1:18.5	1:17.5	1:28.1
	50	6.9	6.9	6.7	7.0	6.5	6.8	6.5	6.8
	SB	73'	80'	88'	98'	82'	89'	69'	97'
Marty Jeffries 7	880	3:57.6	3:55.9	3:29	3:30	3:47.1	3:48.3	3:45.3	3:41.2
	440	1:34.5	1:28.5	1:40.1	1:27.6	1:24.8	1:33.3	1:35.4	1:29.7
	50	7.6	7.6	7.9	7.8	7.6	7.6	7.6	7.7
	SB	77'	79'	86'6"	89'	89'	83'	68'	82'
Stacey Ayrault 8	880	3:59.7	3:43.9	3:35.6	3:35.6	3:35.1	4:06.5	3:46.9	3:21.4
	440	1:42	1:31	1:39.7	1:22.9	1:32.4	1:34.2	1:40.3	1:27.3
	50	7.5	7.8	7.9	7.4	7.3	7.6	7.5	7.5
	SB	66'	73'	88'	82'	71'	82'	79'	81'
Debbie Beach 9	880	3:38.5	3:14.7	cramp 3:23.8	3:19	3:15.1	3:14.2	3:07.7	3:10.4
	440	1:24.2	1:20.1	1:21.1	1:20.6	1:21.2	1:24.5	1:20.6	1:23.9
	50	7.2	7.2	7.1	7.0	6.9	7.1	7.0	7.2
	SB	130'	130'	132'6"	137'	129'	132'	125'	119'
Julie Van Kleeck 10	880	3:33	3:14.6	3:10.9	3:05.8	3:33.9	3:17.3	3:20	3:09.9
	440	1:23.9	1:18.2	1:19.1	1:15.2	1:25.3	1:19.6	1:21.9	1:18.4
	50	7.2	7.2	6.9	7.0	7.1	6.9	6.8	6.5
	SB	91'	110'	113'	122'	104'	119'	107'	105'

Debbie, Wendy, Marty - stomach cramps on 880 - last four trials

All headaches 1st time sea level after running

Stacey - stomachache 2nd sea level

Subjects		Event	Altitude 4/8	4/21	5/13	5/27	Sea Level 4/15	4/28	5/6	5/20
Erin Kenney	2	880	3:13.9	3:05.6	3:02.7	3:00.6	3:05.4	3:13.4	3:01.1	3:06.8
		440	1:23.3	1:16.3	1:18.6	1:16.4	1:21.4	1:21.8	1:21.7	1:20.7
		50	7.7	7.8	7.5	7.8	7.4	7.2	7.5	7.5
		SB	75'	64'	67'	68'6"	67'	61'	69'	78'
Wendy McHalffey	4	880	3:45.5	3:45.4	3:39	3:23	3:28.3	3:45	3:34.8	3:21.4
		440	1:29	1:30.7	1:33.6	1:25.1	1:28.3	1:30.7	1:33.5	1:27.4
		50	7.3	7.8	8.0	7.7	7.4	7.5	7.4	7.6
		SB	77'	78'	83'	88'	85'	85'	81'	83'
Connie Smith	5	880	4:08.9	3:43	4:02.9	3:49.4	3:45	3:57	3:43.8	3:43.1
		440	1:39.7	1:33.3	1:39.2	1:35.9	1:39.1	1:43.1	1:44.1	1:46.1
		50	8.2	8.2	7.7	7.9	7.8	7.7	8.0	7.9
		SB	64'	64'	58'	54'	55'	55'	54'	51'

RELATIVE HUMIDITY

Dry-bulb Thermometer Degrees Fahrenheit	Differences Between Dry-bulb and Wet-bulb Thermometers																			
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°	19°	20°
50	93	87	80	74	67	61	55	50	44	38	33	27	22	16	11	6	1	0		
52	94	87	81	75	69	63	57	51	46	40	35	30	24	20	15	10	5	0		
54	94	88	82	76	70	64	59	53	48	43	38	32	28	23	18	13	8	4		
56	94	88	82	77	71	65	60	55	50	44	40	35	30	25	21	16	12	8		
58	94	89	83	78	72	67	61	56	51	46	42	37	33	28	24	19	15	11		
60	94	89	84	78	73	68	63	58	53	48	44	39	34	30	26	22	18	14		
62	95	89	84	79	74	69	64	59	54	50	45	41	37	32	28	24	20	16		
64	95	90	85	79	74	70	65	60	56	51	47	43	38	34	30	27	23	19		
66	95	90	85	80	75	71	66	61	57	53	49	45	40	36	32	29	25	22		
68	95	90	85	81	76	71	67	63	58	54	50	46	42	38	34	31	27	24		
70	95	90	86	81	77	72	68	64	60	55	52	48	44	40	36	33	29	26		
72	95	91	86	82	77	73	69	65	61	57	53	49	45	42	38	35	31	28		
74	95	91	87	82	78	74	70	66	62	58	54	50	47	43	40	36	33	30		
76	95	91	87	82	78	74	70	66	63	59	55	52	48	45	41	38	35	31		
78	96	91	87	83	79	75	71	67	63	60	56	53	49	46	43	39	35	33		
80	96	92	87	83	79	75	72	68	64	61	57	54	51	47	44	41	38	35		
82	96	92	88	84	80	76	73	69	65	62	58	55	52	48	45	42	40	37	35	33

Taken from George Mallinson and Fred Meppelink Jr., "Science in Modern Life," Ginn & Company, N. Y., 1964, p. 276.

BAY AREA AIR POLLUTION CONTROL DISTRICT

SAN FRANCISCO, CALIFORNIA 94109

INFORMATION BULLETIN 5-70

COMBINED POLLUTANT INDEX EXPERIENCE

1969

By

TECHNICAL SERVICES DIVISION

Summary

A combined pollutant index for the Bay Area has been developed which includes the major contaminants emitted or formed in the atmosphere: oxidant, carbon monoxide, nitrogen dioxide and visibility reducing particulates. The oxidant and particulate components have been weighted because of their contribution to air pollution effects. Values are calculated each day from maximum levels of these contaminants in the north, central and south areas of the District, and three separate index values are released at 4:00 p.m.

The 1969 experience shows percentage occurrences in the "heavy" air pollution category as 0.5% north, 1% central and 4% south. The percentage occurrence of "clean" air was 46% in the north and central areas and 30% in the south.

COMBINED POLLUTANT INDEX EXPERIENCE

1969

1. Introduction

In 1968, the Bay Area Air Pollution Control District established a Combined Pollutant Index to better describe the concentration of air contaminants present in the atmosphere on any given day - summer or winter. As explained in Information Bulletin 10-68, this index is designed to inform the public of gross pollutant levels, and has no intrinsic scientific meaning. Its primary purpose is to provide a numerical value to the total quantity of air pollutants experienced in the Bay Area, of which the previously emphasized oxidant index is only a part.

The widespread use of the word "smog" as a synonym for oxidant has led to public misunderstanding and confusion, particularly in the winter when substantial visibility reduction can occur without oxidant being present. On such days, members of the public and the press are confused to learn that the "smog reading" (the popular term for oxidant readings) is low even when visibility-reducing air pollution is obviously present.

Although there are numerical values assigned to contaminants other than oxidant, they have not been widely publicized or understood. This is due to the fact that adverse levels vary widely between these pollutants, and are related to cumulative effects over different time periods. For example, the State Air

Resources Board has defined the adverse oxidant level as .10 ppm high-hour values occurring on 3 consecutive days or on 7 days in a 90-day period, while the adverse level for nitrogen dioxide is .25 ppm for one hour, and the adverse level for carbon monoxide is 20 ppm averaged over 8 consecutive hours. Thus a simple daily index appeared a highly desirable service to the public interest.

2. Choice of Contaminants

The contaminants included in the combined index are oxidant, carbon monoxide, nitrogen dioxide and particulates (as measured by coefficient of haze). As the definitive element of photochemical smog, oxidant is included and given double weight. Two other gaseous contaminants for which State standards have been established, NO_2 and CO, are included. (Sulfur dioxide is a problem in only one section of the District, and would be misleading in comparable area-wide indexes.) The State standard for particulate matter is 60 $\mu g/m^3$ annual geometric mean, or 100 $\mu g/m^3$ 24-hour average, but these measurements require laboratory analysis and are not available the same day. Thus the District has employed the Coefficient of Haze (COH) as the best available measurement of particulate pollution for which direct and objective readings are available.

All of the contaminants selected have identifiable health effects and two of them, NO_2 and particulate matter, contribute to visibility effects.

(17)

3. <u>Calculation of index</u>

Each day indexes are calculated for three geographic parts of the District:

NACPI - North Area Combined Pollutant Index
San Rafael, Richmond and Pittsburg stations

CACPI - Central Area Combined Pollutant Index
San Francisco and Oakland stations

SACPI - South Area Combined Pollutant Index
Redwood City and San Jose stations.

When full stations are activated in Livermore and Walnut Creek in future years, a fourth area index will be inaugurated: EACPI - East Area Combined Pollutant Index.

The formula for the index is:

$$CPI = 2\ (Ox) + (NO_2) + (CO) + 10\ (COH)$$

where

Ox is the high-hour oxidant in pphm

NO_2 " " " " NO_2 " "

CO " " " " CO " ppm

COH is 8-12 a.m. coefficient of haze value

For each area the greatest <u>high-hour</u> value of oxidant, CO and NO_2 reported by <u>any</u> station in that area is used. The 0800-1200 COH value is used. Since this is an informational rather than a research tool, only those values available by 4:00 p.m. in the afternoon telephone round-up are incorporated.

4. Combined Pollutant Index Data

Since the Combined Pollutant Index became fully operational late in 1968 on a seven-day-a-week basis, 1969 provides the first full year of CPI data. The monthly and annual minimum average, and maximum CPI values for the three sectors are summarized in Table 1. Monthly minimums range from 11 to 22, with annual lows of 11 for all three sectors. Monthly averages range from 21 in the North area for June to 57 for the South area in November. The annual averages are 28 North, 30 Central, and 35 South. Monthly maximums range from 36 in the North in June to 121 in the Central area in September, with annual maximums of 93 North, 121 Central, and 100 South.

5. Classification of CPI Levels

An arbitrary scale of values was tentatively set for interpreting the CPI levels. This scale was as follows:

0 - 25	Clean Air
26 - 50	Light Air Pollution
51 - 75	Moderate Air Pollution
76 - 100	Heavy Air Pollution
101 or greater	Severe Air Pollution

The percentage occurrences in these categories for the North, Central, and South areas in 1969 are given in Table 2. It may be noted that one severe category day in a 30-day month gives 3.33% occurrence and one in a 365-day year gives 0.27%

occurrence. One September day in the Central area reached a "severe" level, giving the percentages shown.

Percentage occurrences in the "heavy" category were 0.5% North, 1% Central and 4% South. In the "moderate" category they were 6% North, 8% Central, and 17% South. Thus the totals of significant pollution at a moderate or greater level were 6.5% North, 9% Central, and 21% South. Only in October did the Central area exceed the South in its "moderate or greater" occurrence, although on September 25th it did have the single most adverse day.

The percentage occurrence of "clean air" was 46% in the North and Central areas, and 30% in the South. The "light" category occurred at frequencies of 48% North, 45% Central, and 49% South. The "light" category, however, is the least well established, as well as the most frequent category. Since individual contaminants are log-normally distributed, the CPI values were expected to be similarly distributed. A log-probability graph demonstrated that they were so distributed, and that over 30% of total days show CPI values between 26 and 35. Such days generally have low to moderate values of individual contaminants, do not approach any adverse levels, and show little if any visibility reduction. If this largest portion of the distribution curve were more properly classed as "clean air", the days in the "clean air" category would reach 76% in the North and Central areas, and 60% in the South area.

The actual contaminant levels which go to make up one of our "heavy" or "severe" CPI days is also a matter of interest. In 1969 there were 9 days with a CPI of 76 or greater (8 of them occurring in the fall season). The average contaminant levels in adversely affected sectors of the District on these days were as follows:

Oxidant	.13 ppm
Nitrogen dioxide	.23 ppm
Carbon monoxide	16 ppm
Coefficient of Haze	2.3

This oxidant level is above the new .10 ppm State standard, the nitrogen dioxide level is slightly below the .25 ppm standard, and the carbon monoxide level is well below the standard of 20 ppm for 8 hours. The coefficient of haze value cannot be directly translated to the suspended particulates daily standard of 100 $\mu g/m^3$, since it records only the darker particulates. In addition, suspended particulates are measured over a 24-hour period whereas the COH value is taken over a 4-hour period. However, measurements for suspended particulates on 7 of the 9 days showed an average of 114 $\mu g/m^3$, which is above the standard of 100 $\mu g/m^3$.

Since health effects are associated with long-term exposures to contaminants above the air quality standards, one cannot make definitive statements concerning health effects associated with these 9 occurrences in 1969. However, one can reasonably conclude that CPI values greater than 76 are associated with one or more contaminants above the air quality standard.

JSS:fm
4/28/70

TABLE 1

MINIMUM, AVERAGE, AND MAXIMUM VALUES OF COMBINED POLLUTANT INDEX BY MONTH FOR NORTH, CENTRAL, AND SOUTH DISTRICTS 1969

	Min.			Avg.			Max.		
	N	C	S	N	C	S	N	C	S
Jan	11	16	11	24	27	28	48	52	52
Feb	11	15	15	24	25	22	41	43	49
Mar	16	16	17	27	28	31	58	57	69
Apr	16	13	18	26	22	27	41	49	49
May	14	11	16	25	24	30	52	48	69
Jun	11	14	13	21	23	24	36	37	43
Jul	12	12	20	26	25	37	72	68	77
Aug	14	18	18	33	34	44	58	64	74
Sep	14	16	20	32	34	45	69	121	84
Oct	18	19	22	38	40	41	93	88	84
Nov	18	20	20	39	46	57	57	87	100
Dec	13	16	14	27	31	34	64	84	77
Annual	11	11	11	28	30	35	93	121	100

TABLE 2

PERCENTAGE OCCURRENCE OF COMBINED POLLUTANT INDEX CATEGORIES FOR NORTH, CENTRAL AND SOUTH DISTRICT 1969

	Clean			Light			Moderate			Heavy			Severe		
	N	C	S	N	C	S	N	C	S	N	C	S	N	C	S
Jan	61	39	48	39	58	42	0	3	10	0	0	0	0	0	0
Feb	61	68	75	39	32	25	0	0	0	0	0	0	0	0	0
Mar	48	45	48	49	52	45	3	3	7	0	0	0	0	0	0
Apr	53	77	43	47	23	57	0	0	0	0	0	0	0	0	0
May	61	71	32	36	29	65	3	0	3	0	0	0	0	0	0
Jun	77	73	43	23	27	57	0	0	0	0	0	0	0	0	0
Jul	52	71	3	42	22	84	3	7	13	3	0	0	0	0	0
Aug	23	23	7	70	67	52	7	10	36	0	0	7	0	0	0
Sep	27	23	13	66	73	33	7	3	47	0	0	7	0	3	0
Oct	19	6	10	55	65	67	23	23	10	3	7	13	0	0	0
Nov	10	10	7	73	40	7	17	43	73	0	7	17	0	0	0
Dec	61	42	42	33	42	39	7	13	13	0	3	7	0	0	0
Annual	46	46	30	48	45	49	6	8	17	0.5	1	4	0	*	0

* Less than 0.5%