The Effect of Humidity

ON NERVOUSNESS AND ON GENERAL EFFICIENCY

BY

LORLE IDA STECHER, A.M.

REPRINTED FROM

ARCHIVES OF PSYCHOLOGY

NO. 38

Submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy in the Faculty of Philosophy, Columbia University

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PREFACE

The following study is part of an extensive investigation of the subject of ventilation in its various biological and mechanical aspects, carried on during the years 1913–1916 by the New York State Commission on Ventilation.[1] This Commission, appointed by the Governor of the State of New York at the request of the New York Association for Improving the Condition of the Poor, was enabled to carry on its work by the aid of the Elizabeth Milbank Anderson Fund. The other psychological experiments of the Commission, which were, like this one, planned by Professor Edward L. Thorndike and carried out under his direction, are described in full in a recent number of the Teachers College Contributions to Education, and briefly reviewed in the historical section of this monograph.

From the foregoing statement of the place of this study in the series of psychological investigations already made by the Commission, it will be evident how deeply the writer is indebted to Professor Thorndike for guidance and advice. She has great pleasure, moreover, in acknowledging her obligation to Professors J. McKeen Cattell, Robert S. Woodworth and Harry L. Hollingworth. Her thanks are also due Mr. George T. Palmer, Chief of the Investigating Staff, and Mr. Joseph Herzstein, Secretary of the Commission.

[1] Members of the Commission: Professor Charles-E. A. Winslow, Professor Frederick S. Lee, Professor Edward L. Thorndike, Mr. D. D. Kimball, Dr. James Alexander Miller, Professor Earle B. Phelps.

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THE EFFECT OF HUMIDITY ON NERVOUSNESS AND ON GENERAL EFFICIENCY

CHAPTER I

History of Investigations of the Effect of Indoor and Outdoor Atmospheric Conditions

The question of how man is affected by climate and by the weather has been a fruitful subject of discussion alike for philosophers and village wiseacres in all ages. In modern times we have found a new topic for general conversation in the subject of the effects of the indoor weather for which our heating and ventilating systems are responsible. Fortunately we are beginning to substitute a scientific treatment of the matter for the old speculative method.

It is evident that the problems connected with ventilation have been seriously considered only in modern times. The first aim of civilized man has always been to get warm air, rather than "good" air. Even the highly cultivated Greeks and Romans, whose extravagance and splendor were pointed out to us in our early classical education, never got beyond the problem of heating, and solved that rather badly.[1] In general, their heating arrangements were no different in principle from those of the Iroquois Indians or the Laplanders, who light a fire in the center of the apartment and let the smoke find its way out by a hole in the roof. Since the ancients commonly set braziers of burning charcoal about the room, the indoor smoke nuisance was never done away with, as is shown by the fact that Marcus Vitruvius Pollio in his De Architectura about 13–16 B.C. recommended dark mural decorations that would not be stained by smoke. The walls and floors of Roman palaces and baths were later heated by means of a network of flues leading from a central fire. Even with this hypocaust[2] system, ventilation was provided only by vent holes in the roof. The use of the chimney

[1] Cf. Bernan, Walter, "History of the Art of Heating and Ventilating," London, 1845. Cf. Joly, "Traité du Chauffage, de la Ventilation," Paris, 1873. Cf. Billings, "Ventilation and Heating," New York, 1893.

[2] Article Hypocausis in Dictionnaire des Antiquités (Daremberg et Saglio) Paris, 1899, 3[1].

even in Italy does not seem to have been common before the twelfth century, and a deliberate attempt to ventilate a house is not recorded until 1660, when Sir Christopher Wren devised a very inferior plan for the House of Parliament.

Of course the phenomena accompanying the crowding of many living beings in a confined space had long been observed, but an explanation of the matter was not soon found. The ancients, according to Weisman,[3] generally attributed the death of animals confined in a closed space to the warming of the air. In 1674 Mayow taught that there was a "principle" in air, capable of supporting life and combustion. Lee[4] quoted him as ascribing the death of animals confined within closed spaces to their consumption of the "nitro-aerial spirit" of the air. "Boyle in 1680 showed that air must be constantly renewed to maintain life. Veratti in 1750 raised the question as to whether death in a confined space was caused by the diminution of the elasticity of the air or by a poisonous exhalation, which, leaving the body of the animal through respiration, carried with it a noxious principle, or by the destruction of the vital principle of the air. With reference to exhalations from the body, Bergman . . . writing in 1791 states: 'The lungs moreover add by their constant motion, various subtle particles by means of the absorbing vessels, and again by the exhaling vessels, carry off others.' . . . Writing of the effects of vitiation of air upon animals, Lavoisier states: 'If one encloses animals in a given quantity of air, they perish in it when they have absorbed or converted into carbon dioxide the greater part of the respirable portions of the air. To make respirable the vitiated air two things must be done: First, to remove from this air by the lime or caustic alkali, the portion of carbon dioxide that it encloses; second, to return to it a quantity of air that is eminently respirable equal to that which it has lost.' "[5]

The Oxygen and the Carbon Dioxide Theories

This statement of Lavoisier's formulates two of the earliest scientific theories of the harmful factors in bad ventilation, *i. e.*, the deficiency-of-oxygen theory and the superabundance-of-carbon-dioxide theory. Many experimenters from the time of Leblanc (1842) on, have found that the diminution of oxygen and the

[3] Weisman, Charles, "Biochemical Studies of Expired Air in Relation to Ventilation," Columbia University Dissertation, New York, 1913. (Excellent bibliography and review of literature. Only references not included in Weisman's study will be cited here.)

[4] Lee, Frederic S., "Laboratory Experiments with Air," *Journal of American Medical Association*, Nov. 7, 1914, **63**, 1625–8. (Short bibliography.)

[5] Quoted from Weisman.

increase of carbon dioxide in the worst ventilated and crowded places is not very large, and is in any event far below the threshold of harmful physiological effects. Nevertheless it appears from the report of Peclet on the construction of a prison in Paris—a work that probably gave the first stimulus to the scientific treatment of the ventilation problem—that as early as 1843 to 1845 the carbon dioxide content of the air had been used as a measure for the efficiency of ventilation. Von Pettenkofer[6] in 1862–63, while demonstrating that the symptoms produced in crowded, ill-ventilated places were due neither to excess of carbon dioxide nor to deficiency of oxygen, nevertheless emphasized the doctrine still held by our sanitary engineers, that the percentage of carbon dioxide is a guide to the other deleterious properties of the atmosphere. A score of experiments lasting up to our own time has now just about eliminated the carbon dioxide and oxygen factors from the question.

The Organic Poison Theory

This brings us to the third great theory that attempts to account for the ill effects of bad ventilation. As early as 1808 we find a reference to the elusive "organic poison" many investigators have tried to isolate. At that time Robertson wrote:[7] " 'Dr. Guthrie found that the moisture frozen on the insides of the windows of Petersburgh, during the winter, is highly volatile; and on being thawed, it gives out a gas equally pernicious, and in other respects possessing similar properties to those of carbonic acid gas.' " Experiments during the latter half of the nineteenth century sometimes substantiated the organic poison theory, and sometimes contradicted it. The work of the most famous supporters of the theory, Brown-Sequard and D'Arsonval (1887), has inspired many later investigators to attack the problem. The decisive results of Hill,[8] D. R. Lucas,[9] and Charles Weisman, working independently in 1913, have made the organic poison theory appear exceedingly improbable.

The Heat and Humidity Theory

The chemical theories of ventilation effects have now been replaced by a physical theory, first suggested by Hermans (1883),

[6] Von Pettenkofer, M., *Liebig's Annalen*, 1862–1863, Suppl. Vol. 2, 1.

[7] Quoted from Weisman.

[8] Hill, Flack, McIntosh, Rowlands and Walker, "The Influence of the Atmosphere on our Health and Comfort in Confined and Crowded Places," *Smithsonian Misc. Collections*, 1913, 60, No. 23.

[9] Lucas, D. R., "Investigation on Proteid Substances in Respired Air," Report of the Committee on School Inquiry, New York City, 1911–1913, 3, 670–688.

who, observing the rise of his temperature in crowded places, and the discomfort that some subjects felt on entering an experimental chamber that had just been used, attributed these effects to the inability of the body to cool itself because of the surrounding elevated temperature and humidity.

Before proceeding with this review of ventilation literature, it might be well to explain further this physical theory, and also the concept of "relative humidity." The living body produces a certain amount of heat, giving off the excess to the surrounding atmosphere through radiation, convection, conduction through the clothing, and evaporation from the surface of the lungs and skin. If the surrounding air is too moist, evaporation can not go on. The amount of moisture which will prevent sufficient evaporation to cool the body is not, however, a question of the absolute amount of moisture in the air at any particular temperature, but of the relative humidity for that temperature. There is for every temperature a saturation point; when that is reached the air cannot take up any more moisture, and any superabundance of moisture will be precipitated. The relative humidity of the air at any particular temperature is the amount of water vapor that the air actually does contain, in proportion to what it would hold if it were completely saturated. As the percentage of saturation for air of a certain temperature becomes higher, the capacity of that air for absorbing more moisture from the skin and lungs becomes less. Conversely, when the air is but little saturated, it has a positive avidity for moisture, taking it from the skin, the membranes of the nose and throat, the eyes, etc.[10]

Continuing our survey of the ventilation experiments, we find that the general reaction of the human organism to moist air has been rather thoroughly studied by physiologists and hygienists. Lehmann and Jessen, in their work of 1890, pointed out that the physical factors of high temperature, high humidity and air motion play just as important a part as the composition of the air.

Rübner and von Lewaschew[11] (1897) contributed data on the relation between the moisture and temperature of the air, the elimination of water and carbon dioxide from the body, and the adaptability of man to high and low temperatures.

[10] Relative humidity is determined in engineering practice by the relation between the readings of the wet-bulb and the dry-bulb or ordinary type of thermometer. In the wet-bulb thermometer, the bulb is covered with thin muslin or silk, soaked in pure water. The evaporation of the water cools the bulb. The position of the mercury on such an instrument depends on the temperature of the air and on the amount of evaporation of water from the bulb cover, which varies inversely with the amount of moisture already in the air.

[11] *Archiv. f. Hyg.*, 1897, 29, 1.

The Oxford school—Handane,[12] Smith, Pembrey, Collis, Boycott, Cadman—have reported (1905–1911) observations made not only in the laboratory but also in cotton-weaving sheds, where the air is artificially humidified with steam, and in mines, where the temperature and humidity are notoriously high.

The Breslau school,—Flügge, Heymann, Paul, Ercklentz—reported in 1905 investigations on human beings, some in good health and others in various pathological conditions, confined in a 3 cu. meter glass experimental chamber under varying conditions of temperature, moisture and humidity. These experimenters also used psychological tests in studying the ventilation conditions. Paul conducted an experiment in a school-room in which fifty or sixty children were kept continuously for two or three hours, at a temperature below 19° C. (about 66° F.) and a humidity not exceeding 50 per cent. No unpleasant symptoms occurred with either teacher or children, in spite of the decided increase in the gaseous products of respiration, and no fatigue as shown by computation tests could be detected. In a series of chamber-tests, Paul found that as a result of confinement for three to four hours, though the carbon dioxide content rose to 10–15 parts in 10,000 (the normal is 4 parts in 10,000) the subjects did not experience any ill effects when the temperature and humidity were kept low. Psychological observations of æsthesiometer, tonometer, ergograph, completion-test and computation performances also showed normal under these conditions. With, however, a chamber-temperature of 26° C. (about 79° F.), 50 per cent. humidity, and with a temperature of 24° C. (about 75° F.), 75 per cent. humidity, the subjects felt headache, depression, etc., and, even before these subjective phenomena, showed increased body temperature as an objective effect. When the air of the chamber was set in motion (thus permitting the body to cool), without altering the chemical composition of the air, the physiological disturbances were immediately removed. When a subject breathed the fresh outside air by keeping his head outside the chamber, or inspiring through a tube coming from outside the chamber, he felt no relief of discomfort. On the other hand, if the body of the subject was placed outside the chamber, no discomfort was observed when the vitiated air of the chamber was inhaled through a tube, though the odor was annoying.

Ercklentz performed similar experiments on diseased persons, finding them more or less sensitive than normal individuals at the same temperature and humidity, according to the character of the disease.

[12] Haldane, *Journal Hyg.*, 1905, 5, 494. Haldane, Pembrey, Collis, Boycott and Cadman, Rep. Dept. Com. on Humidity and Ventilation in Cotton Weaving Sheds, London, 1909 and 1911.

Benedict and Milner (1907) reporting the results of an experiment on the metabolism of matter and energy in the human body, found incidentally that persons could remain for days in a stagnant atmosphere if the air was kept cool and dry.

The later experiments of Hill and his co-workers[13] (1913) corroborate the depressing effect of warm, moist conditions. To quote Hill's description:

"In one class of experiments we shut within the chamber seven or eight students for about half an hour and observed the effect of the confined atmosphere upon them. We kept them therein until the CO_2 reached 3 to 4 per cent. (300 to 400 parts in 10,000) and the oxygen had fallen to from 17 to 16 per cent. The wet-bulb temperature rose meanwhile to about 80 to 85 degrees F. and the dry-bulb a degree or two higher. The students went in chatting and laughing, but by and by as the temperature rose they ceased to talk and their faces became flushed and moist. We have watched them trying to light a cigarette (to relieve the monotony of the experiment) and puzzled by their matches going out, borrowing another, only in vain. They had not sensed the percentage of the diminution of oxygen, which fell below 17. Their breathing was slightly deepened by the high percentage of CO_2, but no headache occurred in any of them from the short exposure to from 3 to 4 per cent. CO_2. Their discomfort was relieved to an astonishing extent by putting on the electric fans placed in the roof. Whilst the air was kept stirred the students were not affected by the oppressive atmosphere. They begged for the fans to be put on when they were cut off. The same old stale air containing 3 to 4 per cent. CO_2 and 16 to 17 per cent. oxygen was whirled, but the movement of the air gave complete relief, because the air was 80 to 85 degrees F. (wet bulb) while the air enmeshed in their clothes in contact with their skin was 98 to 99 degrees F. (wet bulb). . . . One student breathed the air from outside the chamber through a tube and felt little relief. L. H. standing outside, breathed the air in the chamber through a tube, and felt no discomfort; the only result therefrom was a deepening of the respiration."

A series of studies of ventilation problems in which psychological tests were used, not incidentally, but as an integral part of the experiment, is the previous work done under the direction of Professor Thorndike.[14] Briefly considered this work was as follows:

[13] Hill, Flack, McIntosh, Rowlands and Walker, "The Influence of the Atmosphere on Our Health and Comfort in Confined and Crowded Places," *Smithsonian Misc. Collections*, **60**, No. 23, 1913.

[14] "Ventilation in Relation to Mental Work," ed. by E. L. Thorndike, *Teachers College, Columbia University, N. Y. Contributions to Education, 1916.*

I. *The Effect of Conditions of the Air on Mental Work, the Condition Being Changed Daily* (Thorndike and Chapman).

The following air conditions were studied:

(*a*) No fans, no outside air supplied, relative humidity 80 per cent., temperature 86° F. (30° C.).

(*b*) Four fans, 45 cu. ft. per minute per person.

(*b*) Four fans at high speed, no outside air supplied, relative humidity 80 per cent., temperature 86° F. (30° C.).

(*c*) No fans, 45 cu. ft. per person per minute of outside air, relative humidity 86 per cent., temperature 86° F. (30° C.).

(*d*) No fans, no outside air supplied, relative humidity 50 per cent., temperature 86° F. (30° C.).

(*ê*) No fans, 45 cu. ft. per person per minute of outside air, relative humidity 50 per cent., temperature 68° F. (20° C.).

Four men were tested each week during each of five weeks. Besides registering their opinion as to the air condition by the same scale used in the humidity experiment (cf. p. 35), they were tested with the color-naming test, cancellation of 2's and 3's, hard opposites, addition, mental multiplication of a three-place by a three-place number and typewriting. The experimenters concluded that when a person exerts himself, his achievement is as good under the worst of the above listed conditions as under the best of them.

II. *The Effect of Conditions of the Air upon the Rate of Improvement of Mental Functions* (Thorndike and McCall).

The physical conditions were as listed above, except that each condition lasted one week, and each subject spent one five-day period under a good and one five-day period under a bad condition. Fifteen men were tested with the same tests as in I (except color-naming and opposites) and the experimenters concluded that the temporary efficiency of the work was as good in the worst as in the best conditions, when each condition was maintained four hours daily during the five successive days, and that the improvement made during the work of a bad-condition week was equal to the improvement during the best-condition week.

III. *The Effect of Conditions of the Air upon the Accuracy of Judgment* (Thorndike and McCall).

In experiments I and II the subjects worked presumably with maximum effort, the incentive being their fixed daily wage, the instructions of the experimenter and competition among the subjects. Not only did they have a general notion of how well they were doing in such tests, but each day they were given the scores made on the previous day. In experiment III the nature of the experimental situation did not stimulate effort, but positively encouraged carelessness. Four men were observed during six consecutive days for seven hours a day. The following air conditions were studied:

(*a*) 68° F. (20° C.), 50 per cent., 45 cu. ft., no fans.
(*b*) 86° F. (30° C.), 80 per cent., no air, no fans.
(*c*) 68° F., 50 per cent., 45 cu. ft., no fans.
(*d*) 86° F., 80 per cent., 45 cu. ft., no fans.
(*e*) 75° F. (about 24° C.), 50 per cent., 45 cu. ft., no fans.
(*f*) 86° F., 80 per cent., no air, five fans.

In the "no air" conditions the carbon dioxide rose to 40 parts in 10,000. The psychological work consisted in assigning values to specimens of handwriting and English composition of wide quality range, according to the Thorndike and Hillegas scales. The accuracy of each subject's work was obtained by comparing each rating of a specimen with the known value of that specimen previously obtained by having a great many persons grade the specimens, and averaging their grades for each specimen. The work was monotonous in itself, and barren of interest since the subjects were never given any means of telling how well they were doing. There was no practice effect, or if there was any, it was upset by growing boredom and carelessness. The experimenters concluded that an individual might make very much larger errors at one period than at another, but that the hot, humid, stagnant periods showed no larger errors than the cool, fresh periods. There was no demonstrable effect of heat or carbon dioxide content unless possibly the subjects tended under unfavorable conditions to use more of the period for the work and less for rest, *i. e.*, to use time for frequent brief intermissions in the course of the work, rather than for one long intermission at the close.

IV. *The Effect of Certain Conditions of the Air upon the Choice of Alternatives to Mental Work* (Thorndike and McCall).

The quantity and quality of certain mental products were measured when the subjects were left to their own choice as to how much work they should do.

The physical conditions studied were:

(*a*) 68° F. (20° C.), 50 per cent., sometimes with 30 cu. ft. of outside air, sometimes with no air.
(*b*) 75° F. (about 24° C.), 50 per cent., sometimes with 30 cu. ft. of outside air, sometimes with no air.

The conditions were changed every half day or every three days.

The options were:

For one hour and five minutes,
1. Mental multiplication for small pay.
2. Reading a current novel.
3. Resting.
4. Sleeping.

For one hour and five minutes.
1. Learning to typewrite.
2. Conversing.
3. Doing nothing.
4. Sleeping.

A maximal effort test in addition was also given. As far as the measurements themselves go, the experimenters concluded that heat (1) did not seem to have any effect upon the addition at maximal effort, (2) seemed to lead to the choice of the difficult mental multiplication over reading, rest or sleep, and (3) seemed to lead to the choice of conversation, rest, or sleep over the typewriting. The last occurred only when the 75° and 68° conditions were contrasted on the same day. As the experimenters point out, if the results of this experiment be combined with the results from certain other experiments, the influence of 75° as compared with 68° upon the choice between the work in question and light reading, conversation, rest, or sleep was nil. It is possible to argue from the results that the 75° condition is favorable to the non-muscular mental multiplication, and unfavorable to the more muscular work of typewriting.

Besides the laboratory experiments already reported several studies of psychological interest have been made of the effects of school-room ventilation. One of the earliest of these was made by Bass[15] who experimented with an elementary class in an ordinary fan-ventilated room and a class of approximately equal mental ability in a room submitted to recirculated air and ozone (to mask the odor). Each group was observed for two weeks. Physiological observations were made of body temperature and blood pressure, and psychological observations of division, substitution and ergometer performances. Neither physiological nor psychological measurements showed any reliable difference in the effect of the two air conditions. The psychological results were particularly difficult to interpret because of the large practice effect, yet careful statistical treatment of the data showed no inferiority of the "re-

[15] Bass, "Experiment in School Room Ventilation With Reduced Air Supply Through Individual Ducts," *Trans. Amer. Soc. Heat. and Vent. Engineers*, 1913, 19, 328.

circulated air" group in total amount of work done, rate of improvement or rate of fatigue. A second experiment[16] in which much better records were kept of the actual physical conditions of the rooms resulted in the same absence of significant differences in weight and chest measurements, and in division, substitution and cancellation performances. Since both these experiments were performed with classes whose make-up was not under the control of the experimenters, the results were further obscured by some initial difference in the ability of the test and the control class. This disadvantage was removed and more extensive measurements made in a further research[17] under the direction of the New York State Commission on Ventilation, also concerned with the effects of "fresh" outside and of "recirculated" washed air. The purpose of the experiment was to measure the difference, if any, in the school achievement and rate of learning of school pupils submitted to these two air variables. Eighty-eight pupils who were to begin the work of the sixth grade were tested (September, 1915) with arithmetic, association, visual vocabulary, reading, trabue completion and selection tests. On the basis of these tests they were divided into two groups of the same ability. One of the groups thus formed (F) was subjected to outside ventilation from the time heat was first provided until the close of the term. The other group (R) was subjected to ventilation by recirculation, plus occasional use of outside air, throughout the same period. The teaching was the same for both groups, two teachers dividing the work by subjects taught. The F group was in Room 1 until December and from then on in Room 2; the R group was in Room 2 until December and from then on in Room 1. All measurements were made by the same person, on the same day, under as nearly the same conditions as possible, for both groups. These measurements comprised:

1. Tests of learning or practice experiments in addition, cancellation of letters and digits, finding addresses.
2. The achievement in the regular school work as measured by the regular school examinations planned, given and scored by the teacher. The marks given for September before any ventilation conditions were introduced proved that at the start the F and R groups were in the opinion of the teachers of approximately equal proficiency.

[16] Bass, "The Recirculating of Air in a Schoolroom in Minneapolis," *Trans. Amer. Soc. Heat. and Vent. Engineers*, 1915, **21**, 109. Also Ms. on file with N. Y. State Commission on Ventilation under whose auspices the work was done.

[17] Thorndike, Ruger, McCall, "The Effects of Outside Air and Recirculated Air upon the Intellectual Achievement and Improvement of School Pupils," *School and Society*, 1916, **3**, 679.

3. The six tests used to divide the entire group into two halves of equal intellectual ability repeated at the end of January with material of the same scope and plan and approximate degree of difficulty but different content in detail.
4. Nine other standard tests in arithmetic, spelling, reading and logical acuity given at the beginning and at the end of the experiment.

As a result of these measurements it appeared that the use of recirculated air does not impair the ability or readiness of pupils to learn. In fact measures 1 to 4 resulted in a slight superiority of the R group, although the unreliability of this difference was large. The experiment is being repeated, but in so far as this single experiment may be accepted as the best present evidence, the intellectual progress of children seems not to be impaired by an increase of CO_2 from 8 to 10 parts in 10,000 or by recirculation of washed air to an extent that diminishes the steam consumption by 50 per cent.

In most of the ventilation studies reported in the literature, the humidity factor has not been studied independently. When, moreover, moisture has been taken into account it was always high humidity combined with high heat. So although we now have a considerable amount of data in regard to the effect of excessive moisture, we have very little about the effect of excessive dryness. To get the atmosphere as dry as possible was one of the prime objects with the older writers on heating and ventilating. That the world had recovered from its ancient fear of atmospheric dampness by 1838 is shown by the fact that the British House of Commons was equipped with humidifying apparatus in that year. Since that time, ventilating engineers have become increasingly interested in installing such apparatus, though the profession admits that it has no adequate basis of information as to what specific conditions are most desirable.[18] A search of the medical, psychological and technical literature reveals little real knowledge on the subject. A number of articles seem to indicate that there is some justification for the belief that low relative humidity is undesirable from the point of view of the healthy condition of the membranes of the nose and throat. That is, however, a medical problem that need not concern us here. It is in the field of behavior that one gets the most extravagant statements about the effect of dryness in producing nervousness, irritability, and general inefficiency. This is in the domain of psychology itself; such effects of dryness, if they exist in the extreme form in which they are reported to occur, should

[18] Cf. Lyle, J. J., "Relative Humidity, Its Effect on Comfort and Health," *Transactions Amer. Soc. Heat. and Vent. Engineers*, 1912, 106.

be demonstrable by means of psychological tests. That the effects are thought to be severe and easily discoverable to the most casual observer is shown by the following quotations.

Watt,[19] who is particularly concerned about the matter, says:

"Insanity grows on those who live in hot dry air, do exasperating work, and feel abused. . . . Our country throngs with nervous wrecks. As we progress in wealth and culture the thing becomes more prevalent. Men are breaking down in business by too much attention to it, they think. The real trouble is they are conducting their business in dry hot rooms during the cold months of the year. There they become so weakened that the right air of the warm months does not revive them. . . . The area on earth where the divorce evil is greatest and where the children have least respect for their parents is probably the northern part of the United States, where we have hot dry air in our homes, offices, schools and public places about two-thirds of the year. It makes men and women hanker for something they have not. They are impatient with everything about them, thinking the fault is in the people and in institutions rather than in the atmosphere. . . . Children are especially ungrateful to their parents when kept in these drying kilns which our homes resemble and outdo in their deathly dryness. . . ."

Similar statements are to be found in his chapters on "American dry rot," the "steam-heated woman" and dryness as a cause of the falling-off of church attendance.

In a shorter article,[20] he writes of the effects of humidifying the air with a jet of steam in these terms:

"We avoid hundreds of headaches, we cure stupidity, we permit clearness of thought; we have cut down the number of cases of office discipline more than 75 per cent. since we turned on the steam."

Goldsbury[21] expresses the common opinion about outdoor humidity when he says:

"Later, in moving from the Central West to a dry northern state, I found the atmosphere trying. The skin often had a parched feeling, and the dryness of the lips was a constant annoyance. This effect was so marked that after four years I felt that I must get away to a moister climate. I had a sense of nervous tension and

[19] Watt, Wm. E., "Open Air: A Statement of what is being done and what should be done to secure right air in homes, schools, offices, factories, churches, etc.," The Little Chronicle Co., Chicago, 1910.

[20] Watt, Wm. E., "Humidity and Scholarship in School," *American Physical Education Review*, Nov., 1910, 600.

[21] Goldsbury, P. W., "Humidity and Health," *Boston Medical and Surgical Journal*, Sept. 7, 1911, **165**, No. 10, 366–372.

dreaded passing another winter in the state. Early in December came my opportunity to move away, and on my journey westward I spent a day in Chicago. As I walked along the lake front the 'feel' of the cold, wet air, raw though it was, was one of the most refreshing sensations I ever experienced. I then realized that the improvement I had felt throughout the day was due to the presence of an increase of moisture in the air."

Smith[22] reports the general opinion in regard to indoor humidity thus:

"Moreover, properly moistened indoor atmosphere lacks all the oppressive dry feeling so characteristic of the average artificially heated room, seeming more like the corridor of a well-ventilated hotel. The quieting effect of such an atmosphere is striking. There is an indescribable sense of relaxation and poise, contrasting strongly with the feeling of nervous tension so frequently experienced in overheated dry rooms."

Referring to some experiments conducted by himself, Smith says:

"It was satisfactorily proven that one may live during the coldest weather in a room of 65 degrees F. where the relative humidity is kept at about 60 per cent. During the experiments upon the sensations produced by different percentages of saturation, and in order to obtain the opinions of persons having no knowledge of the existing conditions, one room was equipped with a moistening apparatus and the temperature kept at 65–68 degrees with a relative humidity of about 60 per cent. An adjoining room, without a moistening apparatus and heated by an ordinary steam radiator, had an average temperature of 72–74 degrees, with a relative humidity of 30 per cent. In every instance and without at all knowing what the temperatures were in the two rooms, the opinion was unhesitatingly expressed that the first room was several degrees warmer than the second. . . . The relative humidity is the balance wheel that regulates our comfort at different temperatures in still air. . . . Generally speaking, dry air is an excitant, often causing sleeplessness and irritability accompanied by a drier skin and quickened pulse. Moist air is more of a depressant, producing quiet sleep and slower circulation of the blood."

In the minds of numerous other writers for the technical journals there is no doubt of the effect of dry air in producing nervousness. At least one attempt previous to this one has been made to determine experimentally what is the difference in the effect of moist

[22] Smith, Henry M., "Indoor Humidity," *American Gas Light Journal*, Feb. 27, Mar. 20, Mar. 27, 1905, esp. 490–91.

and dry air. The experiment was conducted at a school in Boston[23] by means of an appropriation set aside by the Schoolhouse Commissioners acting with the School Committee. The experiment covered about three months. One of its objects was "to find whether the mental and physical conditions of the occupants of a school are improved by increasing the relative humidity of the air in the rooms." The classes were so arranged that corresponding grades of pupils occupied similar rooms in each half of the building. "Several classes at one end of a floor were subjected to moist atmosphere and classes at the other end to naturally dry air." As Dr. Harrington, under whose jurisdiction the experiment was conducted, says in a personal letter, "pupils tested in the respective grades corresponded in mentality, physique, and social status with pupils in corresponding grades, *e. g.*, fourth grade pupils in a room located in half of the building submitted to humidification, were compared in mentality, etc., with children in the fourth grade in rooms situated on the side that was not submitted to humidifying conditions. This same plan was followed through all grades. The test given to the children in each grade was the same for pupils in that grade in rooms on both sides of the building. These tests were given at the same hour of the day, and on the same date." Thirty cubic feet of air per minute per occupant was supplied. A record of both the physical condition of the children and the percentage of attendance seemed to show no difference. The experimenters concluded that "on the basis of similar mental tests conducted on both the moist and dry sides of the building, no appreciable difference was found."

Climate

Our summary of the literature relating to the effect of air conditions upon man would not be complete without some reference to the great problem of the influence of climate. The lay opinion that climate has distinct effects upon the health and working ability of man, and that racial characteristics are closely correlated with climate, has been a favorite thesis with many writers. We find speculations on the subject in the works of Hippocrates, Aristotle, Montesquieu, Voltaire, Buffon, Hume, Buckle and Disturnelle. Rätzel in his "Anthropogeographie" gives an outline of the earliest views concerning the effect of climate. From this we see that many things—from the color of man's skin and the contour of his face, to the prevalence of religious ideas and the (supposed) fact that more

[23] Eveleth, Charles F., "Experiments on Humidifying Air at the Oliver Wendell Holmes School," *Trans. Amer. Society Heating and Ventilating Engineers*, 1913, 109–127. Also *Heat. and Ventilating Magazine*, Oct., 1913, **10**, No. 10, 14–19.

twins are born in Egypt than elsewhere—have been explained as an effect of climate. That the humidity factor has been accredited with considerable importance is shown by this statement from Russell.[24] "The quick increase of the temperature of the air and the dryness and sunshine of the spring have the effect of precipitating mental alienation and increasing nerve instability; the organism is least robust when the winter passes away." In recent years we have been getting away from those generalizations about the differences between Northerners and Southerners, the climatic reason for the grimness of the Scot, the reason for our inability to work on certain kinds of days, and so on, and have begun some really scientific studies of the factors involved. Among the most promising of these have been a number of investigations of the working ability of the white man in the tropics. Discussions from the medical and psychological point of view are those by Hellpach[25] and by Berliner.[26]

The beginnings of measurements along the line of the effect of atmospheric conditions were made by Malling-Hansen and by Hösch-Ernst in their study of growth rhythms. Seasonal variations in appetite were observed by Schuyten[27] and by Binet."[28] An extension of the physiological investigations was made by Schuyten and by Lobsien who included in his plan tests of attention and memory as well as tests of muscular strength.

A more elaborate investigation is that of Lehmann and Pedersen[29] who attempted an analysis of the influence of the specific factors in the atmospheric environment, by means of long series of tests in 1904–06. Through weekly tests of about 80 boys 10–14 years of age and daily tests of a smaller number during the greater part of a year they studied the effect of the intensity of the sun's rays, temperature and air pressure upon ergographic performance. With other subjects they conducted experiments in addition and memory for nonsense syllables and upon themselves daily dynamometer tests. Their conclusions, based on careful statistical treatment of their data, are as follows:

[24] Russell, Francis, A. R., "The Atmosphere in Relation to Human Life and Health," *Smithsonian Misc. Collections*, 1896, 1072.

[25] Hellpach, Willy, "Die Geopsychische Erscheinungen Wetter, Klima und Landschaft in ihren Einfluss auf das Seelenleben dargestellt," Leipzig, 1911.

[26] Berliner, B., "Der Einfluss von Klima, Wetter und Jahreszeit auf das Nerven und Seelenleben," *Grenzfragen des Nerven und Seelenlebens*, 1914, 5.

[27] *Paedolog. Jahrb.*, 1908.

[28] "La consommation du pain pendant une année scolaire," *L'année psycholog.*, 1897, 4, 337.

[29] Lehmann, Alfred und Pedersen, R. H., "Das Wetter und unsere Arbeit," *Archiv für die gesamte Psych.*, 1907, 10, 1–104. (Resumé of previous work on seasonal variations.)

The actinic rays of the sun increase muscular strength in proportion to the strength of the rays. Heat has, on the other hand, a different optimum so that higher as well as lower temperatures have an unfavorable action on muscular strength. In January muscular strength begins to increase (despite the low temperature) with the increase in the strength of the light, and this rise continues up to the high temperature of the summer months, June to August. When the temperature sinks in September, the rise of muscular strength begins again. At the end of November, on account of the small light strength, and the low temperature, a standstill or a decrease is noticeable. The muscular strength is in spring directly correlated with the atmospheric pressure, but in the fall seems to be independent of this. A sudden change to a place of lower pressure has no effect upon muscular strength, but the return to a normal pressure causes an increase in strength, which is larger or smaller according to the temperature conditions. Speed in addition is not influenced by changes in atmospheric pressure, but is dependent upon temperature, increasing when the temperature nears an optimum (which is different for different individuals) and decreasing when it leaves this optimum. This optimum is far lower than the optimum for muscular strength. Addition is thus in every way distinguished from the central processes which condition the strength of the grip. Meteorological conditions influence memory for nonsense syllables in the same manner in which they affect muscular strength.

Although this is the most extensive and on the whole the most scientific investigation of the effect of atmospheric conditions upon both muscular and mental work one cannot agree with the explanation of some of the findings. The authors consider that memory for nonsense syllables and addition represent rather dissimilar mental functions, the former being dependent upon the strength of attention, the latter upon the fineness of the psycho-physical organization that has taken place. Their experimental results and also the low correlation between memory and addition which they report lend some support to their theory. Nevertheless as an explanation of the organization of mental activity their mysterious association of memory and muscular strength as "Kraftleistungen" is bound to remain very unconvincing.

Dexter[30] made an empirical study of the mental and physiological effects of meteorological conditions, as revealed in statistics of attendance in certain public schools in New York City during

[30] Dexter, Edwin G., "Conduct and the Weather," *Psychological Review, Monograph Supplement*, No. 10, 1899. "Weather Influences," New York, Macmillan, 1904.

the years 1895–96, deportment of school children in Denver, Colorado, assault and battery arrests in New York City, 1891–97, murders in Denver, 1884–96, discipline in New York City Penitentiary, 1891–97, arrests of the violently insane in New York City, 1891–97, attendance at out-patient department of Roosevelt Hospital, 1893–94, days off duty (supposedly for sickness) of New York City policemen, 1891–95, deaths in New York City, 1886–97, suicides in New York City, 1882–87, arrests for drunkenness in New York City, 1893–95, clerical errors in national banks in New York City, 1896–97. A questionnaire answered by 86 teachers in charge of over 10,000 pupils also furnished some information as to the kind of weather in which the children did their best mental and mechanical work. These teachers reported that in a climate similar to that of New York City, calm, cold and clear days gave the best results and hot, muggy days the worst results.

All the conclusions from the statistical study are based on a comparison of "expectancy" with "occurrence" curves; for example, if a certain percentage of all the days considered lay within a certain five-degree zone of temperature, then that same percentage of a particular crime under consideration should occur on days within that five-degree zone, provided that temperature had no effect. If, however, temperature had an influence it would show out as an excess or deficiency of cases compared with the expected percentage for that particular temperature. The results of the study can be summed up in the following table:

Dexter's conclusions and final explanation of his results are expressed in the statements on page 18.

1. Varying meteorological conditions affect directly, though in different ways, the metabolism of life. (By metabolism of life is meant the process of oxidization of body tissues.) Some weather conditions accelerate the vital processes and others retard them. High temperatures, high winds, (better ventilation), fair days and low humidities have an accelerating effect; in their extreme form they produce too rapid a metabolism to be borne by the depleted organism. On the other hand, low temperatures, calms, high pressures, moist and cloudy days have a retarding effect; in their extreme form they so lessen the production of available energy as to reduce its quantity below the minimum required for life or health; under both extremes we find increased sickness and a high death rate.

2. The reserve energy capable of being utilized for intellectual processes, and activities other than those of the vital organs, is affected most by meteorological changes. The reserve energy is the excess energy not used up in the vegetative processes and so

TABLE SHOWING THE EFFECTS OF METEOROLOGICAL CONDITIONS AS FOUND BY DEXTER

Drawn up from Charts

+ means excess of occurrence over expectancy.
− means deficiency of occurrence compared with expectancy.

Data	*Temperature*			*Barometer*			*Humidity*			*Wind*			*Character of Day*			
	Low	*Med.*	*High*	*Low*	*Med.*	*High*	*Low*	*Med.*	*High*	*Low*	*Med.*	*High*	*Fair*	*Cloudy*	*Wet*	*Dry*
	Worst	Best			Best			Best			Best		Best			Best
School Attendance (Absences) . .																
School Deportment (N. Y. C.) . .	−	+	−	+		−	+		−	−	+	−		−	−	
School Deportment (Denver) . . .	+	−	+	+	−	+	+		−	−		+	+	−	−	
Assault (N. Y. C.)	−		+	+	−	−	+		−	−	+	−		−	−	
Murders (Denver)	−		+	+		−	+			−		+		+	+	
Disorder in Penitetiary	+	−	+	+		−	+		−				+			+
Drunkenness	+		−			+	−		+	−		+	+			+
Insanity	+	−	+	+		−	+		−	−		+	+			+
Policemen off Duty (sickness) . . .	+		−	+	−	+	−	+	−	+	−	+		+	+	
Suicide	+	−	+	−	+	−	+		+	−	+	+	+			+
Hospital Patients (sickness)	+	−	+	+	−	+	−		+	+	−	+		+	+	
Deaths	−		+		no data		−		+	+	−	+	+			+
Clerical Errors	−		+	−	+		+	−	+			−		+	+	

made available for action and for intellectual processes. This reserve energy is subject to a rhythm of exhilaration and depression. There is increased reserve energy under the accelerating weather conditions. Although high temperatures favor metabolism, exceedingly high temperatures cause a vital demand exceeding the production, as is shown by the great increase in deaths and the sudden decrease in assaults for the highest temperatures.

3. The quality of the emotional state is plainly influenced by the weather states.

4. The weather effects upon the reserve energy available for action are of the greatest importance. The hot, humid, cloudy wet days, although making us feel out of sorts and liable to be troublesome, show the least numbers of misdemeanors, owing to the fact that the energy required to carry out the emotion is lacking because of the depleting effect of the weather.

5. Those meteorological conditions which are productive of misconduct in a broad sense of the word, are also productive of health and mental alertness; misconduct is the result of excess reserve energy not directed to some useful purpose.

The part of this work which is of particular interest to us in our consideration of the problem of humidity is the fact that with the classes of disorders considered, low humidity is always associated with that restlessness and nervousness that leads to midsconduct. A glance at the table shows an excess of all forms of active disorder under low humidity, and an excess of sickness, drunkenness, death, and clerical errors at the high humidities. Although Dexter points out the possibility that this may be due to electrical phenomena, he nevertheless feels that dryness in itself is accompanied by excesses in conduct which are indicative of peculiarly unbalanced emotions. He asks the question which is very pertinent to our ventilation study: "If such be true for our out-of-door conditions, why not for indoor? How much of our instability of temper is due to furnace heat and a crackling air?"

It is impossible to give an adequate presentation of this piece of work without showing at the same time the charts upon which the conclusions are based. Nor is it quite fair to group the results as has been done in our table, since a shift of a few meteorological groups will make the middle region begin and end at different places, and often reverse the meaning of the phenomenon under discussion. Because of this possibility of confusing the boundaries of the low middle and high regions one can often put upon a chart a construction that does not agree with Dexter's interpretation of the same facts. In any event the excesses or deficiencies over the normal occurrence are small. Without a knowledge of the probable errors it is impossible to tell how significant the differences are, though in many cases they do not seem reliable. This is especially true of curves that waver above and below the normal occurrence line as they pass through the low, medium and high groups, or show distinct sex differences.

Even if we were to grant that the study shows unmistakable effects of various meteorological conditions upon behavior, we should be very cautious about accepting Dexter's conception of the underlying physiological causes. His theory of accelerating and depressing effects, his doctrine of the reserve energy, his blanket explanation of misconduct, nervousness, health and mental alertness are sheer assumptions resulting from the necessity of interpreting the data. We question also the assumption that the number of patients treated in the clinic bears an inverse relation to the number of patients too ill to come out for treatment, and we are inclined to think the explanation of the depressing effect of calms as a ventilation phenomenon on the "deficiency of oxygen" and "superabundance of carbon dioxide" basis, has already been invalidated in the first part of this paper. It is probable that a good many of the phenomena could be less fantastically explained as a simple result of the relative number of people indoors and outdoors during various conditions and their reactions to mere deprivation of outdoor life and relaxation.

Another large-scale empirical study of the effect of climatic conditions is that of Ellsworth Huntington.[31] His general hypothesis is this: "To-day a certain peculiar type of climate prevails wherever civilization is high. In the past the same type seems to have prevailed wherever a great civilization arose. Therefore, such a climate seems to be a necessary condition of great progress." He formulated this hypothesis as the result of a study of the records of many thousands of workers, (1) factory operatives in the cities of New Haven, New Britain, and Bridgeport, Conn., and Pittsburgh, Pennsylvania; (2) operatives in southern cities from Virginia to Florida, and (3) students at the United States Naval Academy at Annapolis, and the Military Academy at West Point. He begins his argument with a chapter entitled "Race or Place," in which he contends, among other things, that the superior energy and initiative of northern peoples compared with southern can be demonstrated through the fact that northern farmers have cleared and improved a greater percentage of their holdings than have southern farmers. Confining our attention to one of his comparisons of

[31] Huntington, Ellsworth, "Civilization and Climate," New Haven, Yale University Press, 1915.

white farmers (pp. 19–20) we find his data[32] to be as follows:

	Northern	*Southern*
Average acreage per farm	92.5	133.4
Average acreage improved land	63.5	45.9
Per cent. of total land improved	69%	34%

It is a startling indictment of the southern climate, if the white man's efficiency has been so lowered; it would seem, however, that this conclusion cannot be drawn in view of the economic and social factors which might prevent the white Southerner from cultivating more of his much larger holdings. The matter of climatic effects is far too complicated to be settled by a simple comparison of percentages of land holdings improved, value of property or value of annual products. Nor will the question be brought any nearer to solution by collecting the opinions of persons who have immigrated to a climate different from that to which they or their ancestors have been accustomed. There is more promise in Huntington's quantitative studies, where the effect of climate in terms of actual accomplishment is noted, quite apart from the subjective effects that have long formed the basis of common opinion about weather influences. In Huntington's chapter "The Effect of the Seasons" he reports the results of an investigation of the daily work of piece-workers in certain New England hardware factories, basing his curves on the average hourly wages of each group of operatives from 1910–13, making allowances for the number of employees and the length of time that they worked. All the figures were reduced to percentages, *i. e.*, if the maximum wage for a group of girls was twelve cents an hour, it was called 100 per cent., while if the maximum wage for a group of men was thirty cents, it also was called 100 per cent. This was done to give the variations in the wages of the girls and the men the same weight in the final computations. The curves obtained by plotting the work of the Connecticut operatives week by week were smoothed and corrected for practice. It appears, then, that all the curves show an extremely low place in mid-winter, and a less pronounced low place in mid-summer, a high point in June, and a still higher point at the end of October. A series of curves representing the work of operatives engaged in making electrical apparatus in a factory in Pittsburgh 1910–13, resemble the Connecticut curves. Curves are also presented for the seasonal variations in the death rate in New York State, 1892–1906, for the increase in weight of tuberculosis patients at Saranac Lake, N. Y., 1893–1902, and for the work (1) of girls in

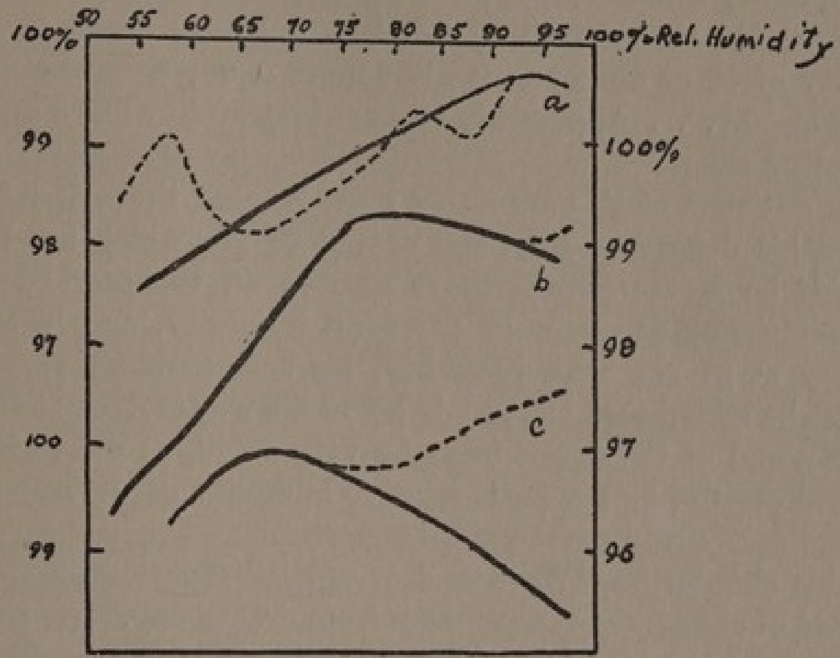
[32] Original data (not percentages) from U. S. Census, 1900.

a tobacco factory at Winston-Salem, N. C., (2) of operatives in cotton factories at Columbia, S. C., and Augusta, Georgia, (3) of carpenters at Jacksonville, Florida, and (4) of cigar makers at Jacksonville and Tampa, Florida.

From an analysis of all these classes of data, including the strength test measurements of Lehmann and Pedersen, Huntington shows that when the summers are particularly favorable and the winters unfavorable, the previously noted seasonal rhythm (maxima of efficiency in June and November) breaks down, and the June maximum and summer minimum disappear. If we go farther south to places where the winters are favorable and the summers very hot, we find a change in the opposite direction, for the summer minimum greatly increases and shoves the two maxima more and more into the winter until the two coalesce; that is, the summer inefficiency lasts for a much longer period and finally gives way to a single maximum in the winter. Because of the mildness of the winters the midwinter drop in efficiency does not take place; instead the curve gradually sinks to the summer level.

So far, Huntington has shown that health and physical activity vary with the seasons. The next problem is to inquire whether mental activity varies in the same way. For this Huntington uses the weekly averages in mathematics for the first-year class at Annapolis for the years 1907–13, the daily marks for the first-year class in English at Annapolis for the year 1912–13, and the daily marks in mathematics for a year and a half, for the classes entering West Point in 1909 and 1910. Measures were taken to eliminate the effect of holidays, examinations, and gradual raising of the faculty standard. From a consideration of these curves, one sees that mental activity resembles physical work in having the two main maxima, except that these two maxima are nearer together and displaced toward the winter. Huntington remarks that this agrees with Lehmann and Pedersen's findings in the case of the addition tests, which also showed the highest efficiency at a lower temperature than that which gave the best results in the strength tests.

In his chapter "The Effect of Humidity and Temperature," Huntington finds no discernible effect of light, in producing the variations of the curve of work. The extent to which people are shut up in their houses also has little influence. Temperature is the most important factor, and in southern New England, low temperature seems to be much more injurious than high. It is the matter of humidity, however, that chiefly concerns us. Huntington has no data on the effect of indoor humidity, but shares the common opinion that the dry air of our buildings during the winter has harmful effects, and is probably an important factor in causing the low efficiency of midwinter. In tracing the relation of work and humidity among factory operatives of Connecticut, he divides the year into (*a*) winter, (*b*) spring and fall, and (*c*) summer, averaging together in each part the work of all the days having a given humidity. Plotting percentages of relative humidity against percentages of efficiency of work (obtained as is explained on p. 21), he gets the following figure.



To quote Huntington's explanation of this figure:

"The heavy solid lines represent what I believe to be the true conditions when other disturbing elements are removed; while the dotted lines show the actual figures. In winter the dampest days are unmistakably the times of greater efficiency. We may shiver when the air is raw, but we work well. The reason is twofold. In general the temperature rises at times of excessive humidity, and this in itself is favorable. Moreover, the air, when taken into the house, does not need to be warmed so much as under other conditions, and thus it remains comparatively moist.

"In spring and fall, when the temperature ranges from freezing to 70° with an average of about 50° F., the best work is performed with a relative humidity of 75 per cent. In other words neither the dry nor the wet days are the best. The summer curve is the most complex of the three. It rises first to a maximum at 60 or 65 per cent., then falls, and once more rises to a higher maximum. The first maximum seems to be due to humidity, the second to temperature. A hot damp day is unquestionably debilitating. The majority of the dampest days in summer, however, are comparatively cool, for they accompany storms. The coolness counterbalances the humidity, and people's efficiency increases. Hence we disregard the right hand maximum and conclude that with an average temperature of 65° a relative humidity of about 60 per cent. is desirable.

"The most unmistakable feature of the curves as a whole is that they show a diminution of work in every way in dry weather. This evidently has a bearing on the low level of the curve of energy in winter. At that season the air in our houses ought to have a humidity of 60 or 65 per cent., but most of the time the figure is only 20 or 30. . . . Apparently this extreme aridity has a markedly debilitating effect."

The criticism of this argument must be that the writer has not justified his departure from the dotted figures which are his real data. If he is not permitted to smooth off the marked rise in winter efficiency at about 57 per cent. humidity, and in summer efficiency at 97 per cent. humidity, his case becomes very weak. It might be added that the reliability of his winter data at the high humidity end of the curve must be very small, as days of 95 per cent. and even of 85 per cent. relative humidity occur very seldom in an ordinarily cold northern winter.

In his chapter on "Work and Weather" Huntington considers the effect of changes of temperature from day to day. He sums the matter up for the Northern States as follows:

"Taking the year as a whole, uniformity of temperature causes low energy; a slight rise is beneficial, but a further rise is of no particular value; the beginning of a fall of temperature is harmful, but when the fall becomes a little larger it is much more stimulating than a rise; when it becomes extreme, however, its beneficial qualities begin to decline."

For the southern latitudes: "The outstanding point is that changes of temperature, provided they are not too great, are more stimulating than uniformity while a fall is more stimulating than a rise." In regard to the effect of the character of the day and its relation to storms, Huntington finds that on tracing efficiency through an average weather cycle such as generally occurs in the region of New England tested, people are usually less efficient on the clear days, moderately efficient on the partly cloudy days, and on the first cloudy day, and most efficient at the end of a storm.

In regard to all his work, Huntington himself admits that "the stimulus of the succession of clear and cloudy days amounts to only 1 per cent. . . . changes of temperature from day to day produce a variation of only a little over 2 per cent. . . . the maximum effect of humidity appears to be only 3 per cent. . . . the effect of the mean temperature upon the girls of Connecticut is 7 per cent. . . . the effect of the seasons reaches nearly 9 per cent. when four years are averaged and nearly 15 per cent. for individual years." As there is no means of finding out what is the reliability of these differences, one cannot say much about their significance. It seems unlikely, however, that any differences except those considered under temperature are real variations in efficiency. The chances are that even these are not to be attributed to temperature alone, but to the fact that temperature acts as the starting point for a whole series of factors in the complicated human situation, such as ill-health, bad housing, economic pressure, and so on, and probably intensifies all of them.

A further division under the general topic of Climate is the whole subject of open air vs. house air. Only the psychological aspects of the matter can here be considered. The problem of the supposed beneficial effects of open air and open window work is one that has agitated school authorities for some time as is shown by the history of the open air school movement.[33] Various attempts have been made to obtain experimental evidence on the question. Among the earliest of these was a study by Roach[34] of increase in weight and improvement in mental performance on the part of a third grade class in a cold-air room compared with a class in a warm room. The experiment, which has been very justly criticized by Whipple[35] on methodological grounds, showed that on the surface of things the fresh air class had the advantage. An extensive experiment still being carried on at the Horace Mann School, Teachers College, Columbia University, has given no justification (except in its first year[36]) for the belief that open air classes do superior mental work as measured by a variety of psychological tests. Recently Bliss[37] reported the results of an experiment with a second, a third, and a fifth grade class in open window rooms with corresponding control classes in well warmed and ventilated school rooms. All pupils were checked upon the matter of

1. Degree of nutrition, measured in terms of weight gained and weight lost.

2. General health, as indicated by the number of children absent because of illness and the total number of days lost thereby.

[33] Upton, "Open Air Schools," *Teachers College Record*, 1914, **15**, No. 3.

[34] Roach, "Revitalizing Devitalized Children," *Amer. Jour. of Pub. Health*, 1913, **3**, No. 2, 13.

[35] Whipple, *Journal of Ed. Psych.*, June, 1913, **4**, 353.

[36] Keyes, "Effect of Outdoor and Indoor School Life on the Physical and Mental Condition of Children," Trans. of Fourth Internat. Congress of School Hygiene, Buffalo, 1913, **2**, 125.

[37] Bliss, "Open Window Classes," *Psychological Clinic*, April 15, 1915, **9**, 29.

3. Mental condition, indicated by the comparative amount of afternoon fatigue in the two classes (tested by checking A's and by arithmetic tests). Comparing the relative number of pounds in weight gained or lost, he found that the open window classes were in general in worse physical condition than the control classes though the number of individuals who gained or lost was distributed about equally between the two classes. The open window classes also had more cases of absence on account of colds, sore throat and contagious diseases. The psychological tests showed no difference in fatigue effect in the two groups. Both open window and control classes improved in cancelling A's in the afternoon and did less well in the addition test. Their curves are almost parallel. The psychological results are obscured by practice and by the unequal initial ability of the two groups, but the conclusion that there is no significant difference in the performance of the two groups is fairly enough drawn.

One comes away from reading the literature with little additional knowledge of what "good" air really is, and little evidence with which to bolster up a belief that "bad" air has a deleterious effect in the laboratory, the school-room or the work-shop of life. In view of the polemics of the fresh air question we shall not attempt any explanation or justification of negative results, but shall go on to a description of the experiment that is the subject of this monograph.

CHAPTER II

General Method of the Humidity Experiment

The experiment was carried on in the laboratory of the New York State Commission on Ventilation. A technical description of the equipment of the plant has been given elsewhere.[1] It will be sufficient for our purposes to say that there was an experimental chamber 10 feet by 14 feet by 10 feet high, and a control room elaborately fitted with heating and cooling devices and with apparatus for humidifying and for drying the air, so that any air condition met in practice could be reproduced, and the different factors of the air environment studied independently.

The experiment lasted from October, 1915, to the end of January, 1916. We had planned to have eight squads of four subjects each, but for various reasons only twenty-nine subjects were actually tested. Because of the unusually high outdoor humidity during the month of October, which made it impossible for the engineers to produce the requisite dryness of the air in the experimental chamber, that month's experiment was regarded as a preliminary study, and the results of the psychological tests for that time are not herein included. During the month of November a moderate degree of dryness was studied, and during December and January the more severe conditions were used.[2]

The squads were designated A to H in chronological order. We observed four subjects during a period of two weeks, the first week under 50 per cent. relative humidity, the second under 20 per cent. The subjects were in the experimental room five days a week from nine until five o'clock, with the exception of three ten-minute recess periods. After a fortnight another squad began under the 20 per cent. condition and spent its second week under the 50 per cent. humidity. This reversal of conditions was designed to equalize the practice effect. The work done by Squad A in its first (wet) week, plus the work done by Squad B in its second (wet) week was compared with the work done by Squad A in its second (dry) week, plus the work done by Squad B in its first (dry) week. The averages derived from these two totals gave a measure of the difference in the

[1] Kimball, D. D., and Palmer, G. T., "Experimental Laboratory of the New York State Commission on Ventilation and Description of the First Year's Work," *Trans. Amer. Soc. Heat. & Vent. Eng.*, 1915, 21, 135.

[2] For chronology and actual physical conditions see Appendix.

effect of the two conditions. We compared the effect of two wet weeks when one squad was at the beginning and the other at the height of its practice curve, with the effect of two dry weeks with practice similarly equalized.

Each new squad came to the laboratory on the Saturday preceding its fortnight's work for instruction and preliminary practice. The experimenter gave each subject a typewritten set of instructions, a copy of which is printed in the Appendix, and went through the daily schedule in shortened time, putting each subject through all the tests, and in the case of the Mental Multiplication and Mirror Tracing tests, making sure that all had a sufficient amount of practice to insure an accomplishment in the Monday test which could be statistically treated.

The subjects for this experiment were young girls (17–18 years of age) recently graduated from the Commercial Department of the Washington Irving High School, New York City. These subjects formed a singularly homogeneous group. They were, with only one exception, of the Hebrew race and almost all lived in the same neighborhood of lower New York. All were intelligent and ambitious; many were going to night school to continue their education along commercial lines, and most of them spent the time between tests in practicing shorthand, doing problems in accounting, or studying various psychological texts that happened to be in the laboratory,—by no means light reading. They were paid for their services and given their luncheons, which were planned by a dietician from Teachers College to furnish 1,000 calories per person per meal.

It may be said here that all record-sheets were open to the inspection of the subjects at all times, and the morning scores were usually ready and entered, before the afternoon tests were taken. The subjects knew, then, just what their standing was in all tests, and were greatly interested in improving their performance. As they understood that the purpose of the experiment was to test the effect of different air conditions upon the efficiency of their work in order that the commission might make recommendations that would help secure better working conditions for children in schools and other workers in offices and factories, they showed a good deal of scientific interest in the problem; in several cases subjects even refused offers of permanent positions in order not to jeopardize the results for their own squad.

Going on now to a description of the actual tests used, we carried on three types of tests: (1) The purely physiological observations of pulse, temperature and eye tremor, (2) The tests of efficiency in mental performances, such as addition and mental multiplication, (3) The tests of motor control and coordination. In addition the subjects' opinions in regard to the air condition and their own comfort were also recorded. Physiological observations have, as has been shown, played a very large part in previous work on ventilation, and are indeed very sensitive indices of any derangement in the heat-regulation of the body. The observation of the tremor of the eyelids squeezed together until they almost meet is in general clinical use as a diagnostic symptom of nervous disorder. We merely standardized the observation somewhat, by using an arbitrary scale for grading the amount of tremor. The addition and multiplication tests were used as examples of purely mental work, where the working of associations was the main issue, and motor exertion was reduced to a minimum. The tests of motor control were as follows:

Industrial Fatigue, to test accuracy of movement in a simple performance, when the speed is kept constant.

Tapping, to test speed in a simple performance in which accuracy is not involved.

Aiming, to test accuracy and speed in a simple performance.

Typewriting, to test accuracy and speed in a complex performance in which the subject is already highly practiced.

Mirror Tracing, to test accuracy primarily, and speed secondarily, in a fairly complex motor performance which the subject had to learn.

Hand and Arm Steadiness, to test control in the face of increasing fatigue.

Reflex Wink, to test change in an instinctive protective reaction. It will, perhaps, give a better idea of the nature of the experiment if these tests are described in the order in which they were given during the day.

The morning began with ten minutes of Addition at maximal effort. The use of continuous addition to test the effects of various outside conditions has been common since Kraepelin first developed his "Rechenhefte" to test the influence of fatigue. The use of computation tests to measure ventilation effects is reported by Flügge, Paul, Ercklentz and Thorndike. In our ten-minute Addition test the amount done in each two-minute interval was marked by the subject as the experimenter called the time. No use has so far been made of the results of this subdivision, its primary aim being to keep the subjects up to their best efforts. For this test the seven addition sheets of Thorndike were used and regularly rotated to prevent memorizing. These furnish material of such nearly equal difficulty that a long series of tests gives comparable results. The experimenter started and stopped the test with a stop-watch. The score for the test was taken as the number of sums obtained minus the incorrect ones. (A specimen blank is printed in the Appendix.)

Directly after the Addition test, before the subjects had moved from their seats, a half-minute pulse reading was taken. Two subjects then took their seats before the two motor boards which were wired together. On these boards was mounted the apparatus for the familiar Aiming, Hand Steadiness and Tapping tests. The history of the use of these tests as indices of motor capacity and control, fatigue, right-handedness, etc., in various comparative investigations in estimating age and sex factors in motor development, and the relation of physical to mental ability, has been so thoroughly discussed by Whipple[3] that a repetition here would be useless. The special form of Three Hole Aiming test used in our experiment was designed by Professor Woodworth and extensively used by him at the World's Fair in 1904. Various forms of the Steadiness test have been in use among physicians since 1888 to detect involuntary movement in paralysis agitans and other diseases. A kind of Arm Steadiness test was used in Dr. S. Weir Mitchell's clinic. The present form of the test seems to have been modified by Professor Woodworth from a test described by Scripture. The Tapping test has been used by many investigators since 1892.

The application by Hollingworth[4] of all three of these tests to his study of the effect of caffein on nervous control is of especial interest to us here. As in Hollingworth's experiment, we obtained the records by means of the Hollerith electric tabulating device in circuit with the apparatus. The use of a kymograph would, of course, have been preferable for accuracy, but with our crowded schedule and the necessity of running off all tests in very short order, the plan was not feasible. In our experiment two subjects were tested together. This factor of competition undoubtedly had a very important effect in stimulating the subjects to exert themselves in each test, and in maintaining interest throughout the long series of tests. A one-minute Aiming test was given to subjects "A" and "B" during which they put the slender point of a metal stylus as rapidly as possible into one after another of three holes arranged in a triangle. Since the electric current had been switched on by the experimenter at the word "Go," each contact of the stylus point with the metal at the bottom of the hole rang up one hit on the electric counter placed in circuit. At the end of

[3] Whipple, Guy M., "Manual of Mental and Physical Tests," 2d ed., Baltimore, Warwick and York, 1914, Part I, 130–151, 155–160.

[4] Hollingworth, H. L., "The Influence of Caffein on Mental and Motor Efficiency," *Archives of Psychology*, 1912, No. 22.

one minute the current for both boards was switched off simultaneously, the counter-reading recorded on the mimeographed record-form for the day, and the test repeated with subjects "C" and "D." Except for the noise incidental in the manipulation of the apparatus, all tests were carried on in rigid silence.

After the Aiming, a one-minute Hand Steadiness test was given. Each of the two subjects held a metal stylus-point, which was $\frac{1}{8}$ inch in diameter, within a $\frac{3}{16}$ inch hole bored in a brass plate. This plate, like the frame into which the Aiming holes were sunk, was inclined at an angle of 45°. The subjects with hand and arm bent into somewhat of a writing position, but entirely unsupported by the table, held the stylus perpendicular to the plane of the inclined plate, and tried to keep the hand so steady that the stylus did not touch the side of the hole. Every such contact caused the counter to register one error. The current was switched on after the subjects were ready with stylus inserted, and switched off before the removal of the stylus.

The next test consisted of an observation of the speed of tapping. The subjects with wrists bound to the edge of the table about an inch lower than the motor board, executed with the stylus a series of rapid taps upon a horizontal metal plate mounted on the board. After three taps the current was turned on and the subjects allowed to tap for one minute, when the current was again cut off.

Next after these motor tests came ten minutes of typewriting. Each girl, using her own Remington no. 6 typewriter, made a facsimile copy of as many pages as possible of fairly homogeneous material arranged from Thorndike's "Principles of Teaching." A credit of 10 was given for each line written, and 1 subtracted for each of about twenty-five possible errors. Since all the subjects were, because of their commercial training, quite skillful in handling the machine, their improvement at least in the early part of this test consisted principally in better adaptation to the particular machine used—a non-visible model with no back-spacer by which mistakes could be covered up.

The Arm Steadiness test, which resembled the Hand Steadiness on a larger scale, followed the typewriting period. This test was given each girl individually for two minutes. She held at shoulder height and arm's length, a slender pointer, at the end of which was inserted a brass rod. The total length of the pointer, including the $4\frac{1}{2}$ inch brass rod, was 40 inches. The subject grasped the pointer with finger-tips just coming up to a line painted on the handle, 5 inches from the end, and tried to hold the end of the brass rod, which was $\frac{3}{16}$ inches in diameter, quite steady within a hole $\frac{5}{8}$ inches in diameter. This hole had been bored out of a thin brass plate, and the plate mounted on a wooden block $\frac{3}{4}$ inch thick. A hole about 2 inches in diameter had then been cleaned out of the block, and the back of the block, opposite the $\frac{5}{8}$ inch test-hole, covered with thin metal. Electrical connections with the counter were arranged so that every contact of the brass pointer-tip with the sides of the hole or with the plate at the back of the hole caused the counter to register one error.

The Arm Steadiness test was followed by a very simple and convenient adaptation of the Mirror Tracing test. For a discussion of previous use of the Mirror Tracing test, the reader is again referred to Whipple.[5] Our apparatus consisted of a star-shaped figure composed of $\frac{3}{16}$ inch metal stripping, sunk flush into the wood base. Each of the twenty sides of the star measured 1 inch, and the ten outside points lay on the circumference of a circle 7 inches in diameter. This star presented a smooth metal design to be traced by the brass stylus. Every time the stylus left the little brass track the circuit was broken, and the counter recorded 1 error. Another error was recorded as the stylus returned to the track. Lifting the point of the stylus was similarly penalized. The subject was instructed to trace the star very accurately and to reduce the errors to a minimum. A credit of 100 was given for each entire tracing of the star during the three-minute test, which meant five for each side or 2.5 for each half side.

After the Mirror Tracing we did twenty minutes of mental multiplication of a three-place by a two-place number. The eight blanks prepared by Professor Thorndike for this purpose have been in use in the laboratory of the Commission for some time and furnish a mental test of a particularly exacting and nerve-racking kind. (A sample blank is printed in the Appendix.) The subjects were required to write the time (hours, minutes and seconds) that it took them to do each line of five examples. This furnished them with an indication of their rate of progress and served to keep interest at a high pitch.

The multiplication was followed by five minutes' work for each girl at the Industrial Fatigue test. The apparatus, which was designed by Bogardus,[6] mimics in simplified form the sort of machine that is used in "speeded-up" industrial operations, like capping tin cans, filling boxes, etc. The test was developed by Bogardus to demonstrate the fatigue resulting from long work at a monotonous motor task when the speed is kept up by some external

[5] Whipple, Guy M., "Manual of Mental and Physical Tests," 2d ed., Baltimore, 1914, Part 2, 119–132.

[6] Bogardus, Emory S., "The Relation of Fatigue to Industrial Accidents," *American Journal of Sociology*, 1911–12, **17**, 206–222, 351–374, 512–539, esp. 362.

agent—a fatigue that greatly increases the probability of mutilating accidents. The test was used in our laboratory with a much shorter observation period, merely as a somewhat simple form of motor and visual coordination test. Our apparatus consisted of a double revolving arm, pivoting at the center, and driven by a small motor. The power was transmitted to the apparatus through a system of pulleys and a speed reducer. Each arm extended about 9 inches from the center, with a 3-inch projection extending downwards. To these projections were fastened 3-inch horizontal sweeps or blades of rather stiff leather. As the arms revolved, these two little sweeps in turn brushed against a 1-inch cube, which the subject set on a 1-inch square painted on the base-board of the apparatus. The subject's procedure was as follows: with her right hand she placed one of the cubes upon the square; then the sweep attached to one arm came around and brushed the cube off the square in the direction of the left hand of the subject. She caught the first cube with her left hand, meanwhile putting the second cube on the square with her right hand. As the second arm brushed off the second cube, she transferred the block just caught in the left hand, to the right hand, placing this block, and again catching the other. This continued for five minutes at a fixed speed which, except for slight variations in the current, was equal to fifteen complete revolutions in twenty-six seconds, or about 346 blocks during the test period. The object of the test was to see how many times the cubes could be put accurately on the square. There were four possibilities of error. A second heavier set of lines $\frac{3}{8}$ of an inch outside the 1-inch square already mentioned, formed a 2-inch square. If a cube was put on so inaccurately that it touched one of the sides of the heavier outer square, 1 error was recorded. If the cube was put on obliquely, so that two of the outer lines were touched, 2 errors were recorded. If an arm hit the hand of the subject as she put on, or caught a block, 3 errors were marked against her. If she failed to put the block on at a time when the sweep was ready to carry the block off, 5 errors were called. If the subject dropped one of the cubes she could always find another on the floor at her side, so that she need not spend time hunting her original block while the 5's were counting up. The fear of losing considerable time through this stooping to get another block acted, however, as an influence in the direction of great accuracy, as did likewise the instinctive fear of getting hit by the revolving arm. The experimenter dictated the errors to an assistant as fast as they were made, counting up totals after the test.

After the Industrial Fatigue test the subjects each took a turn at the apparatus designed to test the control of the protective reflex wink. Partridge,[7] Swift[8] and other experimenters with the reflex wink were mainly interested in noting the length of time it took a subject to gain absolute control of this protective reaction. As it had been found from previous studies that the reaction varies with change in the fixation point, distance of the glass from the eye, intensity of the stimulus and interval between the stimuli, an attempt was made to standardize these conditions. Everything but absolute control was counted as a wink. It often happened that a subject winked with the eye in front of the hammer, although she controlled the winking in the other eye. On that account, only the eye (the right) in front of the hammer was observed. We included this among our tests in an effort to determine whether under the ventilation conditions studied, there would take place any change in the reflex such as would lead one to suspect nervousness. The apparatus consisted of a framed piece of heavy plate glass, 12 × 10 inches, fastened upright to a narrow table. The subject sat on one side of the table, hin rher cesting on a wooden support, her eyes six inches from the glass, her right eye directly opposite the spot where a little fiber-tipped hammer would strike the glass. This hammer was 10 inches long, its head ½ inch in diameter with a rounded point. The hammer struck the center of the glass at a point 20 inches from the table level. The subject fixated a point at the back of the room about 10 feet away. A black curtain, stretched across the glass just below the level of the eyes, concealed from the subject the movements of the experimenter on the other side of the table. After the preparatory signal the experimenter first pulled down to a horizontal position the hammer fastened at the lower edge of the frame, and then released the hammer, which was carried upward by the pull of a small spring. This arrangement provided for giving stimuli of nearly equal intensity. Twenty stimuli were given at prearranged intervals and the number of times the subject reacted to a stimulus by winking was noted. The first stimulus was given directly after the work "Ready." The experimenter recorded whether or not the subject had winked at the stimulus, meanwhile adjusting the hammer with the left hand. Then silently counting from the time the hammer was in position she gave the next stimulus as soon as the required time had elapsed. As the procedure had become practically automatic through long preliminary practice the distribution of stimuli was pretty accurately as follows:

[7] Partridge, Geo. E., "Experiments upon the Control of the Reflex Wink," *Amer. J. of Psychology*, 1899–1900, 11, 244–250.

[8] Swift, Edgar J., "On the Origin and Control of the Reflex Wink," *Amer. J. of Psychology*, 1903, 14, 230–250.

Stimulus 1.	1 second	after "Ready"			
2.	2 seconds	"	stimulus	1	
3.	3 "	"	"	2	
4.	4 "	"	"	3	
5.	5 "	"	"	4	
6.	6 "	"	"	5	
7.	7 "	"	"	6	
8.	8 "	"	"	7	
9.	9 "	"	"	8	
10.	10 "	"	"	9	
11.	1 "	"	"	10	
12.	2 "	"	"	11	
13.	3 "	"	"	12	
14.	4 "	"	"	13	
15.	5 "	"	"	14	
16.	6 "	"	"	15	
17.	1 "	"	"	16	
18.	4 "	"	"	17	
19.	2 "	"	"	18	
20.	5 "	"	"	19	

The sharp, entirely unexpected blow on the glass in front of the subject's eye of course caused her to wink. It was the change in the subject's original reaction that we were interested in.

After the psychological tests had been completed we graded on a scale of from 1 to 5 the amount of tremor of the eyelids, calling no tremor 1 and a very decided flicker of the lids 5. We took another half-minute pulse-count, and also the temperature of the air-space between the skin and the clothing over the chest. The subjects were then asked to write their opinion of the temperature and humidity of the room, and their subjective feeling of comfort in it, according to the following scale:

Comfort.

5. I feel as comfortable as I ever do.
3. I feel about as I usually do at the close of a morning or afternoon of hard mental work.
1. I feel as uncomfortable as I would with a severe headache or an attack of the grippe.
4. My condition is half-way between 3 and 5.
2. My condition is half-way between 1 and 3.

Temperature.

50. Too hot.
40. Too warm.
30. O.K.
20. Too cool.
10. Too cold.

Moisture.

500. Too moist.
400. Moist.
300. O.K.
200. Dry.
100. Too dry.

The results obtained by the use of these scales could then be treated statistically. Luncheon was served to the subjects in the experimental room, and all of the tests were repeated in the afternoon. The schedule of the day was as follows:

9.00 Addition 10′.
9.15 Pulse 30″.
9.25 Aiming, Hand Steadiness, Tapping 1′ each.
9.40 Typewriting 10′.
10.05 Arm Steadiness 2′.
10.25 Mirror Tracing 3′. Recess.
10.55 Mental Multiplication 20′.
11.25 Industrial Fatigue 5′.
11.55 Reflex Wink in 20 stimuli.
12.10 Comfort, Temperature and Moisture Votes. Eyelid tremor.
12.15 Chest Temperature after 10′. Pulse 30″.
12.30 Lunch.
1.10 Recess.
1.20 Addition.
1.35 Aiming, Hand Steadiness, Tapping.
1.55 Typewriting.
2.10 Arm Steadiness.
2.25 Mirror Tracing. Recess.
2.55 Mental Multiplication.
3.20 Industrial Fatigue.
3.55 Reflex Wink.
4.10 Aiming, Hand Steadiness, Tapping, Arm Steadiness.
4.35 Votes. Eyelid tremor.
4.40 Temperature. Pulse.

CHAPTER III

The Effect of Humidity upon Comfort, Pulse and Temperature

As was explained in Chapter II the subjects in our experiment were twice a day required to write their opinion of the air condition under the headings of comfort, temperature and moisture. The results of these comfort votes are shown in Table I.

TABLE I

Average Comfort Vote at 75° F.

Greater Comfort is Indicated by Closer Approximation to 5.

Per Cent. Relative Humidity	*Squads*							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
50	4.63	4.00	3.87	4.33	4.38	4.85	4.18	4.83
45	4.67							
37		4.45						
33			3.97	4.40				
32					4.26		4.30	
21						4.57		
20								4.67

The first column to the left of the table indicates the average relative humidity that actually prevailed; the eight columns to the right indicate by their approximation to 5 a condition of "just-as-usual" comfort. Although the differences are small, they tend to show that under moderate humidity conditions, the subjects felt more comfortable in the drier than in the wetter condition. With greater humidity contrast the subjects (except Squad G) felt more comfortable under the wetter condition.

The results of the temperature votes appear in Table II.

TABLE II

Average Temperature Vote at 75° F.

30 means "O.K." Figures Above 30 Approach "Too Warm." Figures Below 30 Approach "Too Cool"

Relative Humidity	*Squads*							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
50	32.2	30.3	28.0	32.0	30.5	30.25	32.8	31.25
45	31.9							
37		27.8						
33			27.7	32.5				
22					28.5		30.0	
21						29.6		
20								30.25

It seems that the subjects (except Squad D) experienced the wet condition as warmer than the dry condition.

The results of the moisture votes appear in Table III.

TABLE III

Average Moisture Votes at 75° F.

300 means "O.K." Figures Above 300 Approach "Too Moist." Figures Below 300 Approach "Too Dry"

Relative Humidity	*Squads* A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
50	293	273	283	300	305	305	305	305
45	300							
37		295						
33			300	295				
22					298		295	
21						333		
20								298

Apparently the subjects under the earlier moderate humidity contrasts were quite confused in their notions of the prevailing humidity, but Squads D, E, G and H were correct in thinking the 50 per cent. condition more moist.

Table IV shows that the P.E. of the various averages would swamp the differences even where the greatest humidity contrast prevailed. Yet the differences reported are not entirely without significance when it is remembered that these are the opinions of quite naive subjects, totally unaware of the real temperature and humidity prevailing, who recorded their votes at the end of about three and a half hours' exposure to a condition often pronounced excessively damp or dry when they first entered the room.

TABLE IV

P.E. of Average Vote for Squads E, F, G, H

	Wet Average	*Wet* P.E.	*Dry* Average	*Dry* P.E.
Comfort	4.56	.09	4.45	.06
Temperature	31.2	.16	29.59	.24
Moisture	305	0	308	1.06

The results of the physiological observations made in the manner described in Chapter II are reported in Table V.

There is no significant difference between the results for the wet and the dry weeks. The average fall in pulse from the morning to the noon observation is 10.3 for the wet and 9.0 for the dry condition. The average fall in pulse from the morning to the afternoon observation is 5.3 for the wet and 3.4 for the dry. The average rise in temperature from noon to afternoon is 0.6 for the wet and

TABLE V

PHYSIOLOGICAL OBSERVATIONS UNDER 75° F.

Average Temperature in Degrees F. — *Average Pulse in Beats per Minute*

	Wet					Dry				
	Pulse			*Temperature*		*Pulse*			*Temperature*	
Squads	*A.M.*	*Noon*	*P.M.*	*Noon*	*P.M.*	*A.M.*	*Noon*	*P.M.*	*Noon*	*P.M.*
A	90	79	86	93.2	93.5					
A[1]	84	74	82	93.3	93.5					
B	92	81	86	92.8	93.6					
B[1]	93	79	85	93.6	94.2					
C[2]	92	81	86	96.0	96.5	83	74	83	94.1	95.4
D[2]	90	82	83	93.9	94.1	96	84	86	94.0	94.5
E	81	76	83	93.9	94.9	82	73	83	94.8	95.5
F	92	78	88	96.1	97.2	92	83	91	96.4	96.8
G	87	77	79	95.3	95.9	83	73	75	95.2	96.0
H	91	77	82	93.2	93.1	87	82	85	95.0	94.4
Average Last 6 squads	88.8	78.5	83.5	94.7°	95.3°	87.2	78.2	83.8	94.9°	95.4°

0.5 for the dry condition. It appears, then, that these physiological observations reveal no difference in the reaction of the body to the air conditions studied. Possibly more sensitive tests or more rigorous conditions would bring out a difference. It must be remembered in this connection that it was not the purpose of the commission to discover what extremes of humidity could be borne by the human organism. Since the study attempted to solve a practical problem no humidity conditions were used in the laboratory that might not have occurred under ordinary circumstances. As a matter of fact an indoor humidity of 50 per cent. or 20 per cent. would only rarely be found to exist. At least these votes and physiological observations show that for practical purposes the ventilation conditions studied are not noticeably uncomfortable or dangerous to health during the exposure period of this experiment.

[1] Supposed "dry" weeks too moist to be included as dry.

[2] Average humidity in dry weeks 33 per cent.

CHAPTER IV

The Effect of Humidity upon Average Performance and upon Average Improvement from Morning to Afternoon

I. *Average Performance*

To obtain two figures, a comparison of which would directly indicate the effect of the fortnight's exposure to the wet and dry conditions upon any particular test, averages were computed from all the observations upon all the subjects for the wet weeks and from the corresponding observations for the dry weeks. Within each test the effect of the atmospheric condition can be traced in the difference between the average performance for the wet and for the dry periods. This comparison can be made for each of the squad-pairs and for the group of subjects as a whole. The latter comparison is of course a more reliable indication of the ventilation effect since inequalities of practice are better balanced out with the larger group. In making these comparisons it must be remembered that some of the tests give results in terms of simple score or amount done, some in terms of errors, and some in terms of both amount and errors. For the tests which give this double result (Addition, Mirror Tracing, Mental Multiplication, and Typewriting) the most interesting measure of the effect of the ventilation condition is probably the amount with errors subtracted (here called net score), which represents the general efficiency of the function. Table VI presents these comparisons of score, errors, and net score for all the tests.

In the "Average Performance" column, opposite the letters of the paired squads, appears the average for each one-month unit, with practice equalized by the reversal of the order of the ventilation conditions. In the "Average Performance" column opposite the words "Total Number Average" appears the average obtained from adding the net scores for all subjects in that particular test and dividing by the total number of observations involved; opposite the words "Group Average" appears the average obtained by adding the three above-mentioned paired-squad averages and dividing by three. This "Group Average" was computed in order to minimize the labor of calculating the reliability of the figure which was to stand for the ventilation effect. The P.E. of the Group

Average, which is in most cases very similar to the Total Number Average, was obtained by the use of the formulæ:

$$\sigma_{\text{dis.}} = \sqrt{\frac{\Sigma d^2}{n}}$$

$$\sigma_{\text{t.}-\text{obt. av.}} = \frac{\sigma_{\text{dis.}}}{\sqrt{n}}$$

$$\text{P.E.} = .6745\ \sigma_{\text{t.}-\text{obt. av.}}$$

where $\sigma_{\text{dis.}}$ = the mean square deviation of the distribution, the unreliability of whose average is in question,

n = the number of measures in the distribution,

$\sigma_{\text{t.}-\text{obt. av.}}$ = the mean square deviation of the probable divergence of the true from the obtained average.

In the column "Difference between Wet and Dry" appears the simple difference between the averages for the wet and dry conditions. The reliability of the difference between the Group Averages was computed by means of the formulæ:

$$\sigma_{\text{t.}-\text{obt. diff. } W-D} = \sqrt{(\sigma_{\text{t.}-\text{obt. } W})^2 + (\sigma_{\text{t.}-\text{obt. } D})^2}$$

$$\text{P.E.} = .6745\ \sigma_{\text{t.}-\text{obt. diff. } W-D}$$

where

$\sigma_{\text{t.}-\text{obt. diff. } W-D}$ = the mean square deviation of the probable divergence of the true from the obtained difference between the Wet and Dry averages,

$\sigma_{\text{t.}-\text{obt. } W}$(or $\sigma_{\text{t.}-\text{obt. } D}$) = the mean square deviation of the probable divergence of the true from the obtained average for the Wet (or Dry) condition.

A consideration of the measures of Table VI shows that although the averages are quite reliable, even the small widening of the limits of the averages that is indicated by the P.E.'s will cover up the difference in the humidity effect. The same absence of any specific effect of wetness and dryness per se is apparent from the fact that the P.E. of the difference between the wet and dry averages is in most cases larger than the obtained difference.

If, despite the size of the P.E.'s there should appear to be considerable uniformity in the effect of either condition, we might be able to conclude that the ventilation had exerted a small but consistent influence. The column headed "Favorable Condition" shows that for the experiment as a whole no such uniformity exists.

1. For each paired-squad unit the effect is fairly uniform.

C & D are favorably affected by Wet in:	*by Dry in*:
Addition	Aiming
Hand Steadiness	Tapping
Arm Steadiness	Typewriting
Mirror	
Mental Multiplication	
Fatigue	
Wink	
Tremor	

E & F are favorably affected by Wet in:	*by Dry in*:
No case	All cases

G & H are favorably affected by Wet in:	*by Dry in*:
Addition	Mirror
Aiming	Fatigue
Hand Steadiness	Wink
Tapping	
Typewriting	
Arm Steadiness	
Mental Multiplication	

2. The effect is not consistent throughout the experiment. Though the result for the squad-pairs is two out of three in favor of the Wet, we can not ignore the fact that the third case is absolutely in favor of the Dry. It will be remembered that E & F and G & H are more comparable with respect to the dryness obtained (21.5 per cent. and 21 per cent.) than are C & D and G & H (33 per cent. and 21 per cent.); so the association of C & D and G & H cannot be explained on that basis.

3. For the same test we find no case of a uniformly favorable effect of either humidity condition.

Addition	is	favored	by	Wet in	the	case	of	C & D and	G & H
Aiming	"	"	"	Dry "	"	"	"	C & D "	E & F
Hand Steadiness	"	"	"	Wet "	"	"	"	C & D "	G & H
Tapping	"	"	"	Dry "	"	"	"	C & D "	E & F
Typewriting	"	"	"	Dry "	"	"	"	C & D "	E & F
Arm Steadiness	"	"	"	Wet "	"	"	"	C & D "	G & H
Mirror Tracing	"	"	"	Dry "	"	"	"	E & F "	G & H
Mental Multiplication	"	"	"	Wet "	"	"	"	C & D "	G & H
Fatigue	"	"	"	Dry "	"	"	"	E & F "	G & H
Wink	"	"	"	Dry "	"	"	"	E & F "	G & H
Tremor	"	"	"	Wet "	"	"	"	C & D	
Termor	"	"	"	Dry "	"	"	"	E & F	

Tremor is equal for Wet and Dry in the case of G & H.

4. Taking the experiment as a whole there are 33 chances for one or the other condition to predominate. (11 tests for each of 33 squads.) Counting the number of W.'s and D.'s, we find that

in 15 cases Wet is more favorable and in 17 cases Dry is more favorable,—certainly no evidence for a differential effect of the humidity conditions studied.

5. The inconsistency in the effect upon the three squads can, of course, be explained on statistical grounds as a result of differences in initial ability and practice among the subjects. It is only when we take into account the full quota of subjects that these differences are balanced out. Comparing the averages obtained from the total number of trials we find:

Wet is more favorable for:	*Dry is more favorable for:*
Addition	Aiming
Hand Steadiness	Tapping
Typewriting	Arm Steadiness
Mental Multiplication	Mirror Tracing
Fatigue	Wink
	Tremor

Certainly as regards Average Performance, it does not appear that our subjects suffered any disadvantage under the dry condition. It would hardly be safe to make any inference from our data as to the reason why certain of the tests are better performed under one and others under the other condition. Two tests show a more reliable difference than do the rest; these are Hand Steadiness, which is better under the Wet, and Tapping, which is better under the Dry condition.

Since it is possible that the amount produced and the errors might be differently affected by the atmospheric condition, the errors and gross scores were also treated separately. Tables VII and VIII present these comparisons for the Wet and Dry periods. Though it appears that the gross score and errors are not always similarly affected, the detailed analysis of the tables may be omitted in view of the small differences and the large P.E.'s. The largest difference is in the case of Mirror Tracing errors, but even this is only about twice the P.E. In general we find no evidence that average performance is adversely affected by dryness.

II. *Improvement from Morning to Afternoon*

Although the Average Performance under a relatively longer exposure to the two humidity conditions showed no differential effect, it is conceivable that such an effect might take place during the course of the eight hour working day. Computations were accordingly made in order to find out whether there was a consistent lessening of efficiency or increased nervousness in the afternoons of dry weeks as compared with the afternoons of wet weeks.

We computed for each individual in each test the difference between her morning and her last afternoon trial on every day, calling the improvement + if the last trial was really a better performance than the first (*i. e.*, larger net score or fewer errors) and − if deterioration had taken place. These improvements were then algebraically averaged. Table IX presents this comparison. The figures were computed by means of the same formulæ and are to be interpreted in the same way as in the case of the Average Performance, except for the fact that the readings need not be made with reference to score or errors. The difference between the averages for the Wet and for the Dry are somewhat more reliable than in the case of the Average Performance, but still too small to indicate any real difference in the effect of the two conditions upon ability to improve upon the morning performance. Not all paired-squads show improvement in a particular test. Indeed in the Arm Steadiness test there is a consistent deterioration in the afternoon, both in the Wet and in the Dry weeks. In such a case the letter for the condition under which least deterioration took place appears in the "Favorable Condition" column.

1. Running through the same comparisons that were made for the Average Performance, we find that each paired-squad shows the predominating effect of one condition or the other.

C & D are favorably affected by Wet in:	*by Dry in:*
Addition	Hand Steadiness
Aiming	Typewriting
Tapping	Mirror
Arm Steadiness	Mental Multiplication
Fatigue	
Wink	
Tremor	

E & F are favorably affected by Wet in:	*by Dry in:*
Addition	Arm Steadiness
Aiming	Mirror
Hand Steadiness	Fatigue
Tapping	Wink
Typewriting	
Mental Multiplication	
Tremor	

G & H are favorably affected by Wet in:	*by Dry in:*
Tremor	All other cases

2. The squad-pairs do not agree any better than in the case of the Average Performance. C & D and E & F are favored by the Wet, G & H by the Dry. For C & D this was true of the Average Performance also; but E & F and G & H show a reversed effect.

3. For the same test we find two cases of a uniform effect upon all the paired-squads. These are Mirror Tracing, which is favored by Dry, and Eyelid Tremor, which is favored by Wet. The results for the other tests are:

Addition	is favored by Wet in the case of	C & D	and	E & F
Aiming	" " " Wet " " " "	C & D	"	E & F
Hand Steadiness	" " " Dry " " " "	C & D	"	G & H
Tapping	" " " Wet " " " "	C & D	"	E & F
Typewriting	" " " Dry " " " "	C & D	"	G & H
Arm Steadiness	" " " Dry " " " "	E & F	"	G & H
Mental Multiplication	" " " Dry " " " "	C & D	"	G & H
Fatigue	" " " Dry " " " "	E & F	"	G & H
Wink	" " " Dry " " " "	E & F	"	G & H

4. Out of 33 chances, Wet predominates 15 times and Dry 18 times.

5. Considering the Total Number Averages

Wet is more favorable for:	*Dry is more favorable for:*
Addition	Hand Steadiness
Aiming	Tapping
Tremor	Typewriting
	Arm Steadiness
	Mirror
	Mental Multiplication
	Fatigue
	Wink

From this it appears that dryness, instead of exerting a harmful effect, might even be considered to facilitate improvement. Among these tests Mirror Tracing and Industrial Fatigue show the most reliable difference in improvement, both being better under the Dry condition. It will be noted that tests that show a better performance under one condition often show more improvement under the other condition. Only 13 out of 33 cases show a similar effect of either condition on both Average Performance and Average Improvement.

Tables X and XI show that the uncombined gross errors and scores are again not similarly affected by a given condition. The differences between improvement in the Wet and the Dry weeks are too small to be very significant though both Mirror Tracing and Typewriting show a gross score difference that is twice the P.E.

Using the scores and the errors in the tests as described, we can find no reliable general difference between the effect on Average Performance or on Morning to Afternoon Improvement of the 50 per cent. and 20 per cent. relative humidity. An experiment of this sort for this length of time seems to bring out none of the supposed effect of dryness on nervousness and on general efficiency.

TABLE VI

The Effect of 50 Per Cent. and 20 Per Cent. Relative Humidity at 75° F. upon Average Performance

(Net Score or Errors)

Test	*Squad*	*Wet Av. Perform.*	*P.E.*	*Dry Av. Perform.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Net Score)	C & D	93.12		88.00		W		
	E & F	88.57		92.48		D		
	G & H	86.12		83.18		W		
	Tot. No. Av.	89.13		87.67		W	1.46	
	Group Av.	89.27	1.13	87.89	1.48	W	1.38	1.87
Aiming (Score)	C & D	130.01		130.85		D		
	E & F	133.34		137.21		D		
	G & H	129.82		128.70		W		
	Tot. No. Av.	131.00		132.08		D	1.08	
	Group Av.	131.05	.63	132.25	1.41	D	1.20	1.55
Hand Steadiness (Errors)	C & D	9.17		12.36		W		
	E & F	17.08		16.27		D		
	G & H	15.97		24.67		W		
	Tot. No. Av.	14.17		18.07		W	3.90	
	Group Av.	14.07	1.36	17.77	2.00	W	3.70	2.42
Tapping (Score)	C & D	353.19		361.70		D		
	E & F	357.88		365.49		D		
	G & H	359.75		354.86		W		
	Tot. No. Av.	367.07		360.42		D	3.35	
	Group Av.	356.94	1.08	360.68	1.71	D	3.74	2.02

TABLE VI—*Continued*

Test	*Squad*	*Wet Av. Perform.*	*P.E.*	*Dry Av. Perform.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Typewriting (Net Score)	C & D	359.40		361.58		D		
	E & F	325.19		330.65		D		
	G & H	318.92		311.38		W		
	Tot. No. Av.	333.80		333.60		W	.20	
	Group Av.	334.50	6.93	334.54	8.06	D	.04	10.62
Arm Steadiness (Errors)	C & D	15.74		18.83		W		
	E & F	19.45		10.99		D		
	G & H	11.33		14.76		W		
	Tot. No. Av.	15.32		14.87		D	.45	
	Group Av.	15.50	1.29	14.86	1.25	D	.64	1.79
Mirror Tracing (Net Score)	C & D	404.56		331.88		W		
	E & H	288.22		359.04		D		
	G & H	344.66		356.68		D		
	Tot. No. Av.	344.95		349.83		D	4.88	
	Group Av.	345.81	18.56	349.20	4.79	D	3.39	19.14
Mental Multiplication (Net Score)	C & D	194.00		125.31		W		
	E & F	305.11		309.97		D		
	G & H	273.80		259.05		W		
	Tot. No. Av.	257.64		231.07		W	26.57	
	Group Av.	257.63	18.24	231.44	30.37	W	26.19	35.43

TABLE VI—*Concluded*

Test	*Squad*	*Wet Av. Perform.*	*P.E.*	*Dry Av. Perform.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Industrial Fatigue (Errors)	C & D	12.80		16.76		W		
	E & F	15.58		14.91		D		
	G & H	17.98		16.72		D		
	Tot. No. Av.	15.58		16.16		W	.58	
	Group Av.	15.45	.83	16.13	.34	W	.68	.89
Reflex Wink (Errors)	C & D	13.25		13.57		W		
	E & F	15.20		12.77		D		
	G & H	9.88		8.86		D		
	Tot. No. Av.	12.65		11.60		D	1.05	
	Group Av.	12.77	.86	11.73	.80	D	1.04	1.17
Eyelid Tremor (Errors)	C & D	1.47		1.99		W		
	E & F	2.90		2.39		D		
	G & H	2.04		2.04		=		
	Tot. No. Av.	2.14		2.13		D	.01	
	Group Av.	2.13		2.14		W	.01	

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TABLE VII

THE EFFECT OF 50 PER CENT. AND 20 PER CENT. RELATIVE HUMIDITY AT 75° F. UPON AVERAGE PERFORMANCE

(Errors)

Test	*Squad*	*Wet* *Av. Error*	*Wet* *P.E.*	*Dry* *Av. Error*	*Dry* *P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Errors)	C & D	8.31		8.77		W		
	E & F	5.30		4.94		D		
	G & H	5.40		6.78		W		
	Total No. Av.	6.29		6.84		W	.55	
	Group Av.	6.34	.55	6.83	.61	W	.49	.82
Mirror	C & D	78.84		71.37		D		
Tracing (Errors)	E & F	98.90		71.97		D		
	G & H	70.79		74.50		D		
	Total No. Av.	82.34		72.71		D	9.63	
	Group Av.	82.84	4.61	72.61	.53	D	10.23	4.64
Mental Multiplication (Errors)	C & D	47.29		48.11		W		
	E & F	40.17		43.97		W		
	G & H	36.77		33.80		D		
	Total No. Av.	41.41		41.95		W	.54	
	Group Av.	41.41	1.71	41.96	2.35	W	.55	2.90
Typewriting (Errors)	C & D	67.84		61.90		D		
	E & F	37.30		39.20		W		
	G & H	24.11		31.55		W		
	Total No. Av.	42.22		43.72		W	1.50	
	Group Av.	43.08	7.16	44.22	4.18	W	1.14	8.30

TABLE VIII

THE EFFECT OF 50 PER CENT. AND 20 PER CENT. RELATIVE HUMIDITY AT 75° F. UPON AVERAGE PERFORMANCE

(Gross Score)

Test	*Squad*	*Wet Av. Perform.*	*P.E.*	*Dry Av. Perform.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Gross Score)	C & D	101.44		97.06		W		
	E & F	93.87		97.42		D		
	G & H	91.52		90.15		W		
	Total No. Av.	95.43		94.67		W	.76	
	Group Av.	95.61	1.65	94.88	1.32	W	.73	2.11
Mirror Tracing (Gross Score)	C & D	481.91		396.80		W		
	E & F	387.10		431.10		D		
	G & H	415.37		431.56		D		
	Total No. Av.	426.79		420.34		W	6.45	
	Group Av.	428.13	15.53	419.82	6.35	W	8.31	16.74
Mental Multiplication (Gross Score)	C & D	241.29		172.00		W		
	E & F	345.29		354.05		D		
	G & H	312.00		292.86		W		
	Total No. Av.	299.52		272.58		W	26.94	
	Group Av.	299.53	17.08	272.97	29.50	W	26.56	34.09
Typewriting (Gross Score)	C & D	427.23		423.53		W		
	E & F	362.51		369.77		D		
	G & H	343.25		342.89		W		
	Total No. Av.	376.01		377.29		D	1.07	
	Group Av.	377.66	14.04	378.73	13.10	D	1.07	19.17

TABLE IX

THE EFFECT OF 50 PER CENT. AND 20 PER CENT. RELATIVE HUMIDITY AT 75° F. UPON AVERAGE IMPROVEMENT FROM MORNING TO AFTERNOON

(Net Score or Errors)

Test	*Squad*	*Wet* *Av. Improvmt.*	*P.E.*	*Dry* *Av. Improvmt.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Net Score)	C & D	+3.91		+2.11		W		
	E & F	+2.17		+1.73		W		
	G & H	+2.30		+2.89		D		
	Total No. No.	+2.77		+2.28		W	0.49	
	Group Av.	+2.79	.31	+2.24	.19	W	0.55	.36
Aiming (Score)	C & D	+0.04		+0.01		W		
	E & F	+3.27		−3.44		W		
	G & H	+4.47		+5.08		D		
	Total No. Av.	+2.68		+0.75		W	1.93	
	Group Av.	+2.59	.73	+0.55	1.36	W	2.04	1.54
Hand Steadiness (Errors)	C & D	+2.36		+4.24		D		
	E & F	−0.80		−2.40		W		
	G & H	−0.26		+2.83		D		
	Total No. Av.	+0.40		+1.64		D	1.24	
	Group Av.	+0.43	.54	+1.55	1.11	D	1.12	1.23
Tapping (Score)	C & D	+4.41		+2.08		W		
	E & F	+4.18		+2.78		W		
	G & H	−0.96		+9.95		D		
	Total No. Av.	+2.39		+5.14		D	2.75	
	Group Av.	+2.54	.96	+4.93	1.39	D	2.39	1.69

TABLE IX—*Continued*

Test	*Squad*	*Wet* *Av. Improvmt.*	*P.E.*	*Dry* *Av. Improvmt.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Typewriting (Net Score)	C & D	+9.48		+21.34		D		
	E & F	+5.80		+ 3.76		W		
	G & H	−4.25		+ 2.56		D		
	Total No. Av.	+3.32		+ 9.03		D	5.71	
	Group Av.	+3.68	2.26	+ 9.22	3.34	D	5.54	4.04
Arm Steadiness (Errors)	C & D	−1.78		−2.20		W		
	E & F	−2.51		−2.12		D		
	G & H	−2.40		−1.80		D		
	Total No. Av.	−2.24		−2.03		D	0.21	
	Group Av.	−2.23	.13	−2.04	.07	D	0.19	.15
Mirror Tracing (Net Score)	C & D	+19.17		+20.66		D		
	E & F	+17.76		+30.29		D		
	G & H	+20.42		+29.88		D		
	Total No. Av.	+19.42		+27.30		D	8.12	
	Group Av.	+19.12	.42	+26.94	1.73	D	7.82	1.79
Mental Multiplication (Net Score)	C & D	+ 7.54		+ 8.00		D		
	E & H	+23.83		+17.17		W		
	G & H	+ 2.70		+18.68		D		
	Total No. Av.	+11.35		+14.60		D	3.25	
	Group Av.	+11.36	3.53	+14.61	1.84	D	3.25	3.98

TABLE IX—*Concluded*

Test	*Squad*	*Wet* *Av. Improvmt.*	*P.E.*	*Dry* *Av. Improvmt.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Industrial Fatigue (Errors)	C & D	+1.69		+0.25		W		
	E & F	+1.23		+4.14		D		
	G & H	+0.37		+8.30		D		
	Total No. Av.	+1.06		+4.42		D	3.36	
	Group Av.	+1.10	.22	+4.23	1.28	D	3.13	1.30
Reflex Wink (Errors)	C & D	+0.91		+0.23		W		
	E & F	+1.49		+1.91		D		
	G & H	+0.67		+2.17		D		
	Total No. Av.	+1.01		+1.47		D	0.46	
	Group Av.	+1.02	.14	+1.43	.34	D	0.41	.36
Eyelid Tremor (Errors)	C & D	+0.37		+0.08		W		
	E & F	+0.02		0.00		W		
	G & H	+0.32		+0.07		W		
	Total No. Av.	+0.24		+0.06		W	0.18	
	Group Av.	+0.23		+0.05		W	0.18	

+ Indicates better performance (larger net score or fewer errors).
− Indicates worse performance.

TABLE X

THE EFFECT OF 50 PER CENT. AND 20 PER CENT. RELATIVE HUMIDITY AT 75° F. UPON AVERAGE IMPROVEMENT FROM MORNING TO AFTERNOON

(*Errors*)

Test	*Squad*	*Wet* *Av. Improvmt.*	*P.E.*	*Dry* *Av. Improvmt.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Errors)	C & D	+1.09		+0.17		W		
	E & F	+0.32		+0.29		W		
	G & H	+0.35		+0.73		D		
	Total No. Av	+0.57		+0.42		W	.15	
	Group Av.	+0.58	.14	+0.53	.10	W	.05	.16
Mirror Tracing (Errors)	C & D	−5.28		−5.42		W		
	E & F	−5.92		−8.18		W		
	G & H	−4.48		−2.50		D		
	Total No. Av.	−5.19		−5.21		W	.02	
	Group Av.	−5.22	.23	−5.33	.88	W	.11	.91
Mental Multiplication (Errors)	C & D	−1.31		−4.57		W		
	E & F	−1.60		+0.18		D		
	G & H	−0.51		+3.26		D		
	Total No. Av.	−1.14		−0.38		D	.76	
	Group Av.	−1.14	.18	−0.37	1.26	D	.77	1.27
Typewriting (Errors)	C & D	+6.37		+1.23		W		
	E & F	+1.86		+4.88		D		
	G & H	+0.18		−0.31		W		
	Total No. Av.	+2.68		+1.82		W	.86	
	Group Ave.	+2.80	1.02	+1.93	.85	W	.87	1.33

TABLE XI

THE EFFECT OF 50 PER CENT. AND 20 PER CENT. RELATIVE HUMIDITY AT 75° F. UPON AVERAGE IMPROVEMENT FROM MORNING TO AFTERNOON

(*Gross Score*)

Test	*Squad*	*Wet* *Av. Improvmt.*	*P.E.*	*Dry* *Av. Improvmt.*	*P.E.*	*Favorable Condition*	*Diff. between Wet & Dry*	*P.E. of Diff.*
Addition (Gross Score)	C & D	+2.83		+ 1.91		W		
	E & F	+1.86		+ 1.44		W		
	G & H	+1.95		+ 1.77		W		
	Total No. Av.	+2.20		+ 1.72		W	.48	
	Group Av.	+2.21	.17	+ 1.71	.07	W	.50	.18
Mirror Tracing (Gross Score)	C & D	+21.31		+33.05		D		
	E & F	+23.64		+20.93		W		
	G & H	+25.30		+31.89		D		
	Total No. Av.	+23.57		+28.76		D	5.19	
	Group Av.	+23.41	.63	+28.62	2.13	D	5.21	2.21
Mental Multiplication (Gross Score)	C & D	+ 8.86		+ 9.71		D		
	E & F	+25.43		+16.76		W		
	G & H	+ 4.00		+15.43		D		
	Total No. Av.	+12.76		+13.94		D	1.18	
	Group Av.	+12.76	3.58	+13.96	1.19	D	1.20	3.77
Typewriting (Gross Score)	C & D	+3.14		+20.20		D		
	E & F	+3.89		− 0.94		W		
	G & H	−4.45		+ 2.77		D		
	Total No. Av.	+0.62		+ 7.25		D	6.63	
	Group Av.	+0.86	1.47	+ 7.34	3.59	D	6.48	3.88

CHAPTER V

Correlations Among the Tests

The original purpose in working out the correlations was to see whether there existed a body of tests with high inter-correlations that could be used as a composite measure of nervous and motor control. The use of the data without reference to the ventilation conditions under which it was collected is permissible since it was not possible to trace any ventilation effect in the records. Accordingly for every test the data for any one individual were arranged in two equal groups to permit of correction for attenuation due to chance errors, which do not balance out in the case of correlations as in the case of averages, but cause the coefficient to approximate zero. This division into two groups was accomplished by adding alternate tests, putting the trials numbered 1 into Group I, the trials numbered 2 into Group II. The following table shows the chronological position of tests added to form Group I and Group II for every individual in every test, the procedure varying somewhat according to whether there were two or three tests a day.

	A.M.	*P.M.*	*A.M.*	*P.M.*$_{\text{I}}$	*P.M.*$_{\text{II}}$
Monday	1	2	1	2	1
Tuesday	2	1	2	1	2
Wednesday	1	2	1	2	1
Thursday	2	1	2	1	2
Friday	1	2	1	2	1
Monday	2	1	2	1	2
Tuesday	1	2	1	2	1
Wednesday	2	1	2	1	2
Thursday	1	2	1	2	1
Friday	2	1	2	1	2

On the few occasions when a test in one group was missing, the corresponding test was dropped from the second group. An average was computed for each individual in both groups of every test and these averages treated as the original measures to which was applied the Pearson correlation formula:

$$\frac{\Sigma X \cdot Y}{\sqrt{\Sigma X^2} \cdot \sqrt{\Sigma Y^2}}$$

and the Spearman correction formula used by Thorndike in the shortened form:

$$r_{pq} = \frac{\sqrt{(r_{p1q2})(r_{p2q1})}}{\sqrt{(r_{p1p2})(r_{q1q2})}}$$

That is, to obtain the corrected r between Addition and Multiplication the four raw coefficients of correlation used in the correction formula were:

1) the r of Group I of Addition with Group II of Multiplication
2) the r of Group II of Addition with Group I of Multiplication
3) the r of Group I of Addition with Group II of Addition
4) the r of Group I of Multiplication with Group II of Multiplication

The P.E.'s of the raw coefficients were computed by means of the formula:

$$\text{P.E.}_r = .6745\frac{1 - r^2}{\sqrt{n}}$$

The number of cases for all the correlations was 21.

It should be explained that the signs of the deviation in the case of tests that gave a result in terms of errors, were changed so that a positive correlation always means the correlation between good performances.

Table XII shows the raw correlations for the two groups arranged as explained above, together with their reliability. Table XIII shows the corrected coefficients, and also the average of the two raw group-coefficients. It will be noted that the correction does not raise the coefficient very much. Indeed the usefulness of correcting for attenuation when a long series of measurements has been made would be doubtful did not the method furnish a check upon the reliability of the work. The blanks in the corrected coefficient triangle represent practically a zero correlation; in those cases the correction formula could not be applied because the raw coefficients were themselves of unlike sign. All the coefficients were worked out to three places, the two-place figure in the tables being always an approximation. Table XIV shows the correlations of the Fatigue test whose inter-group or reliability coefficient was only .24. Table XV shows the average correlation of each test with all the others.

Eight things are noteworthy about the correlations. Unless otherwise stated, the reference is to corrected correlations.

1. The high raw correlations between the two groups arranged from data of the same test. They range from .90 to .99. The only exception is the Industrial Fatigue test whose correlations are given in a separate table. Since chance is so largely operative in

determining an individual's performance in this test as given in our experiment, it cannot be regarded as a useful measure, nor can much confidence be placed in the amounts of its correlation with other tests.

2. The low correlations among tests that might in a common sense way be taken as measures of the same sort of motor ability. The more reliable correlations of this sort are:

Aiming with Tapping	.31
Aiming with Wink	.27
Hand Steadiness with Typewriting	.23
Hand Steadiness with Tremor	.21
Tapping with Typewriting	.18
Tapping with Mirror	.15
Tapping with Tremor	.22
Typewriting with Arm Steadiness	.30
Typewriting with Mirror	.38

3. The indifferent correlations among tests that one would expect to be functionally connected:

Aiming with Mirror	−.10
Aiming with Tremor	−.04 and .02 (raw)
Hand Steadiness with Tapping	.07
Hand Steadiness with Mirror	.13
Hand Steadiness with Wink	−.10
Tapping with Arm Steadiness	−.01 and .07 (raw)
Tapping with Wink	−.09
Typewriting with Tremor	−.08
Arm Steadiness with Tremor	−.05
Arm Steadiness with Mirror	.02 and −.01 (raw)
Mirror with Wink	−.13
Mirror with Tremor	.12
Wink with Tremor	.13

4. The rather curious negative correlations between tests of supposedly related motor abilities:

Aiming with Typewriting	−.35
Aiming with Arm Steadiness	−.45
Aiming with Hand Steadiness	−.42
Typewriting with Wink	−.31
Arm Steadiness with Wink	−.48

5. The low correlation between the two intellectual tests,

Addition and Mental Multiplication	.22

6. The fact that Addition gives a reliably positive correlation with only two tests aside from Mental Multiplication,

Addition with Hand Steadiness.......... .24
Addition with Typewriting.............. .15

7. The fact that no motor test gives a reliable positive correlation with Mental Multiplication, and the fact that Mental Multiplication is negative with Hand Steadiness − .15, and more strongly negative with Tapping − .24, with Arm Steadiness − .32, and with Tremor − .49.

8. The low negative correlation between Hand and Arm Steadiness − .16 which is a surprising thing in view of the fact that these two tests almost always correlate in like manner with other tests, and would presumably test the same sort of function.

To bring together this loosely connected group of correlations into any sort of consistent scheme is almost impossible. These conclusions can be drawn:

1. The distinction between the purely intellectual Mental Multiplication and the motor tests, particularly the inverse relation with those designed especially to test nervous control—Hand Steadiness, Arm Steadiness, Tremor—seems evident. We should not, however, lay much weight upon this apparent motor incapacity of the more intellectually gifted until this point has been specifically investigated with different groups of subjects.

2. Addition is not an intellectual performance of the same order as Mental Multiplication as is shown by its incomplete resemblance to Mental Multiplication .22, and by its tendency to correlate positively with many of the motor tests to which Multiplication is opposed.

3. Typewriting seems to hold a sort of intermediate position between a purely intellectual and a purely motor test; it shows an indifferent correlation with Multiplication, a low positive correlation with Addition and higher positive correlation with four motor tests.

4. Mirror Tracing seems to be somewhat the same sort of Test as Typewriting as is shown by the fact that it correlates .38 and shows, in common with Typewriting, positive (though lower) correlations with Addition, Hand Steadiness, Tapping and Mental Multiplication.

The relations among the more highly correlated tests appear in diagrams A and B, in which + bonds indicate reliable positive correlations between tests. Only tests directly connected by + bonds correlate positively; reliable negative correlations are indicated by − bonds.

DIAGRAM A

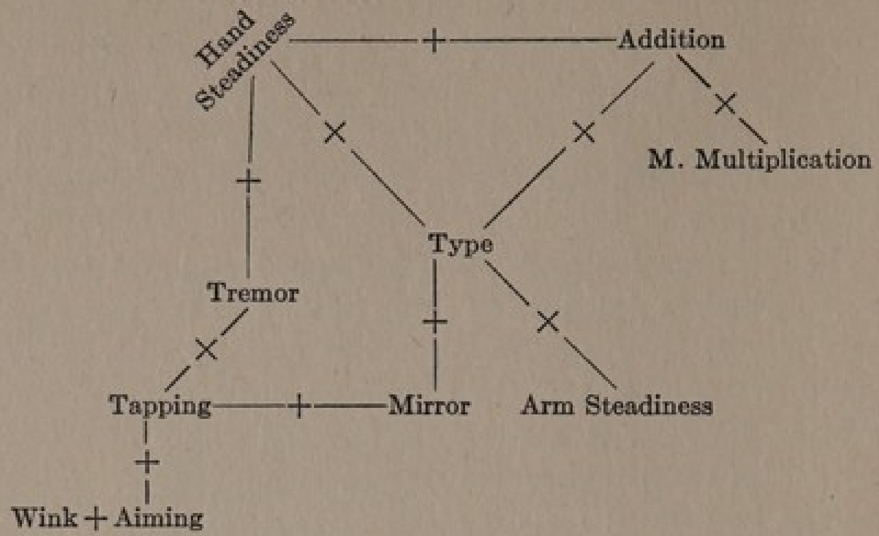
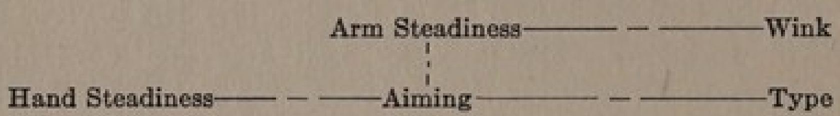


DIAGRAM B



How to account for the antagonism between Aiming and the other tests is an unsolved problem. The connection between Typewriting, Mirror Tracing and the other motor tests is intelligible, since they obviously have common motor elements. According to the table of average correlations, Mirror Tracing shows the closest connection with the rest of our group of tests; next come Typewriting and Tapping, then Addition and lastly Hand Steadiness. Wink, Arm Steadiness and Aiming are negative in that order, Tremor being practically zero. The only conclusion that can be drawn from these correlations is that ability in these tests of nervous and motor control seems to be a good deal more specialized than we have previously believed to be the case.

If we attempt to compare these correlations with those found by other investigators we find that although there is an enormous literature[1] on the subject, motor tests such as those examined in this study have only rarely been used in other researches.

Burt[2] found corrected correlations for Mirror Tracing with Tapping of .48 in an elementary school and 1.00 in a preparatory school. Although our method for both tests differed somewhat from that of Burt, we found a much lower coefficient, .15.

[1] Simpson, "Correlations of Mental Abilities," *Teachers College, Columbia University, Contributions to Education*, 1912, No. 53. Giese, "Korrelationen psychischer Functionen," *Ztschr. f. angew. Psych.*, 1915, 10, 193.

[2] Burt, "Experimental Tests of General Intelligence," *Brit. J. Psych.*, 1909, 3, 94.

Hollingworth[3] reported an interesting series of correlations for subjects who almost reached the limit of improvement. Correlations computed for the 1st, 5th, 25th, 80th, and 205th trials showed, contrary to the findings of Binet and Burt and in agreement with those of Spearman, that coefficients become positive and tend to become greater the longer the practice is continued. Hollingworth inclines to the theory that variability is reduced, and ability more and more accurately measured as the individual nears his ultimate capacity. Our data has not yet been worked up in regard to this problem; the correlations reported in this chapter were computed from measures at about the middle of the fortnight's practice curve. Not all of Hollingworth's series showed the type of change demanded by his theory. For example, Addition with the Three Hole Aiming test correlated: — .21, .32, .22, .19, .16. Our two group correlations are: — .11 and .01. Hollingworth's correlations for Addition and Tapping were: .45, .55, .49, .55, .57. Ours are: —. 16 and — .05. Hollingworth's correlations for Tapping and Aiming were — .25, .50, .13, .26, .39. Ours are: .32 and .26. Thus it appears that our negative results for Addition and Tapping are completely at variance with the high positive ones of Hollingworth. In the other two cases our coefficients approximate some one of Hollingworth's. A matter which can produce such startling effects on the size of coefficients certainly merits very special investigation.

A comparison between our results and those of Chapman[4] can be made on the point of the correlation between Addition and Mental Multiplication. He found as group coefficients — .02 and .02, a practically indifferent correlation, whereas ours are .23 and .20. Chapman's correlations were between initial abilities and ours between average abilities, which might possibly account for the difference.

The correlation between Tapping and Addition reported by Giese[5] agrees closely with Hollingworth's findings, .42 for men and .38 for women. Possibly all these differences will eventually be explained on the basis of selection. With our present knowledge of the subject of correlation we can do little more than echo Brown's[6] philosophical conclusions: "The correlation between different

[3] Hollingworth, "Correlation of Abilities as Affected by Practice," *J. Ed. Psych.*, 1913, 4, 405.

[4] Chapman, "Individual Differences in Ability and Improvement and Their Correlations," New York, *Teachers College, Columbia University, Contributions to Education*, 1914, No. 63.

[5] Giese, "Korrelationen psychischer Functionen," *Ztschr. f. angew. Psych.*, 1915, 10, 193.

[6] Brown, "The Essentials of Mental Measurement," London, Cambridge Univ. Press, 1911.

TABLE XII

Raw Correlations of the Two Groups (Upper Right Hand Triangle)
P.E. of the Raw Coefficients (Lower Left Hand Triangle)

	Addition		*Aiming*		*Hand Steadiness*		*Tapping*		*Type-writing*		*Arm Steadiness*		*Mirror*		*Multi-plication*		*Wink*		*Tremor*	
	I	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*	*I*	*II*
Addition II			−.11		.23		−.16		.19		.05		.16		.20		−.14		−.09	
" I				.01		.24		−.05		.12		.08		.11		.23		−.15		−.06
Aiming II	.15				−.41		.32		−.34		−.38		−.07		−.09		.22		−.04	
" I		.15				−.39		.26		−.34		−.49		−.14		0		.32		.02
Hand Steadiness II	.14		.12				.03		.22		−.15		.13		−.14		−.09		.20	
" " I		.14		.12				.18		.24		−.16		.12		−.16		−.11		.19
Tapping II	.15		.14		.14				.24		−.01		.20		−.28		−.09		.26	
" I		.14		.13		.15				.12		.07		.11		−.20		−.08		.16
Typewriting II	.15		.13		.14		.14				.29		.32		.04		−.33		−.13	
" I		.14		.13		.14		.14				.30		.42		−.02		−.29		−.04
Arm Steadiness II	.15		.11		.14		.15		.13				−.01		−.31		−.47		−.04	
" " I		.15		.13		.14		.15		.13				.02		−.32		−.48		−.06
Mirror II	.15		.14		.14		.15		.12		.15				.15		−.15		.09	
" I		.14		.15		.14		.14		.13		.15				.12		−.11		.14
Multiplication II	.14		.15		.14		.14		.15		.13		.15				.01		−.47	
" I		.14		.15		.14		.14		.15		.13		.14				.02		−.46
Wink II	.14		.13		.15		.15		.13		.11		.15		.15				.09	
" I		.14		.14		.15		.15		.13		.11		.14		.15				.16
Tremor II	.15		.15		.14		.14		.15		.15		.14		.12		.14			
" I		.15		.15		.14		.14		.14		.15		.15		.11		.15		

psychical abilities is not very close. . . . The size of the correlation coefficient varies greatly from one group of subjects to another. This shows how great is the danger of spurious correlation due to heterogeneity of material. . . . Correlations may be very low even within a set of mental tests which appear to measure closely related mental abilities, and this when the reliability coefficients are high."

TABLE XII(*a*)

INTER-GROUP CORRELATIONS AND THEIR RELIABILITY

	r Group I and Group II	P.E.
Addition	.96	.01
Aiming	.93	.02
Hand Steadiness	.98	.004
Tapping	.96	.01
Typewriting	.99	.002
Arm Steadiness	.99	.002
Mirror Tracing	.96	.01
Multiplication	.99	.002
Reflex Wink	.99	.003
Eyelid Tremor	.90	.03

TABLE XIII

Raw Correlations (Average of the two Group Correlations of Table XII) in Upper Right Hand Triangle. Corrected Correlations in Lower Left Hand Triangle

	Addition	*Aiming*	*Hand Steadiness*	*Tapping*	*Type-writing*	*Arm Steadiness*	*Mirror*	*Multi-plication*	*Wink*	*Tremor*
Addition		−.10	.23	−.11	.15	.07	.14	.21	−.15	−.07
Aiming			−.40	.29	−.34	−.44	−.10	.04	.27	−.01
Hand Steadiness	.24	−.42		.10	.23	−.16	.13	−.15	−.10	.20
Tapping	−.09	.31	.07		.18	.03	.15	−.24	−.09	.21
Typewriting	.15	−.35	.23	.18		.29	.37	.01	−.31	−.08
Arm Steadiness	.06	−.45	−.16		.30		.01	−.32	−.47	−.05
Mirror	.14	−.10	.13	.15	.38			.13	−.13	.12
Multiplication	.22		−.15	−.24		−.32	.14		.01	−.46
Wink	−.15	.27	−.10	−.09	−.31	−.48	−.13	0		.12
Tremor	−.08		.21	.22	−.08	−.05	.12	−.49	.13	

Note: As the correlations were originally worked out to the third place this average will not exactly equal the average of the two-place coefficients of Table XII.

TABLE XIV

RAW CORRELATIONS OF FATIGUE WITH OTHER TESTS. P.E. ABOUT .15

	Fatigue I	Fatigue II
Addition II	.37	
" I		.26
Aiming II	−.38	
" I		−.21
Hand Steadiness II	0	
" " I		.34
Tapping II	.05	
" I		.32
Typewriting II	.24	
" I		.12
Arm Steadiness II	.09	
" " I		.02
Mirror II	.14	
" I		.48
Multiplication II	−.02	
" I		.33
Wink II	−.05	
" I		−.30
Tremor II	−.11	
" I		−.06
Fatigue II	.24	
" I		.24

TABLE XV

AVERAGE CORRELATION OF EACH TEST WITH ALL THE OTHERS

Computed from corrected correlations

Addition	.05
Aiming	−.08
Hand Steadiness	.01
Tapping	.06
Typewriting	.06
Arm Steadiness	−.12
Mirror Tracing	.09
Mental Multiplication	−.10
Wink	−.16
Tremor	0

CHAPTER VI

Practice Effect During a Fortnight and Variations in Efficiency During the Working Day

I. *Practice Effect During a Fortnight*

The general situation in our experiment was particularly favorable for a comparison of the shape of the practice curves in eight of our tests. Although a fortnight is unfortunately rather a short practice period, still the regularity of the daily procedure and the homogeneity of the groups of subjects make the results quite reliable.

The tests studied with reference to the practice curve present an interesting group for comparison since they comprise:

(*a*) a motor test in which a new and difficult hand and eye coordination is learned (Mirror Tracing), a motor test of a function in which the subjects were already considerably practiced (Typewriting), a mental test in which a new and difficult process is learned (Mental Multiplication), a mental test of a process in which the subjects have had a good deal of practice (Addition), and

(*b*) four tests of relatively simple sensori-motor functions in which the possibility of improvement is much more limited by physiological factors (Hand Steadiness, Arm Steadiness, Tapping, Aiming).

The first group (*a*) was given twice a day to each subject, the second group (*b*) three times a day. In studying each test, the data for all our subjects were amalgamated to give a fortnight's practice curve. Table XVI and Graph I represent these curves for the tests that were given morning and afternoon; Table XVII and Graph II represent the curves for the tests given morning, early afternoon and late afternoon. The abscissæ represent successive practice periods throughout the two weeks, the ordinates represent actual products (net score) except in the case of the two Steadiness tests, where errors are plotted, the direction of the curves being simply reversed to permit of comparison with the curves of product. Each point on the curve is the average of the records of all subjects for the test at that particular practice period.

No intensive discussion of these curves will be attempted. The whole subject of the shape of the practice curve and its dependence upon the order, difficulty and time of formation of bonds has been examined at length by Thorndike in his analysis of "Changes in the Rate of Improvement."[1] It will be of interest, however, to note certain characteristic differences in the shape of the curves. From a consideration of these tables and graphs it appears that:

1. The four simple sensori-motor tests show very similar curves.

2. Aiming and Steadiness during the first three days show an initial acceleration in all cases followed by a very gradual rise.

3. Tapping, among the motor tests, comes nearest to showing a rectilinear relation between product and time spent in practice.

4. The two Steadiness tests show a practice level by Wednesday of the second week.

5. Tapping and Aiming resemble each other more than they resemble the Steadiness tests.

6. The simple motor tests are much more variable than the intellectual tests. The convexity of the curve and the variability of the performance in Typewriting show the degree of its partial relationship with both the intellectual and the motor tests.

For all these the initial rise probably represents the adjustment to the new apparatus and to the general laboratory situation. The fact of variability is probably to be interpreted in the light of the possibility of further improvement which is naturally small in such narrow performances as Aiming, Tapping, and Steadiness, and could not have been great in Typewriting since these subjects had had a considerable amount of practice.

7. Addition shows a surprising amount of improvement considering the fact that these subjects (high school graduates) had already had a long experience with numbers, and that they had had specific training in bookkeeping.

8. Since there is no possibility of reaching the limit of improvement in a complex function like Mental Multiplication in the 400 minutes of actual practice time, this curve shows a somewhat more rectilinear relation between product and time. There is a slight acceleration at the beginning and then a rapid rise to the end of the experiment.

9. Mirror Tracing seems to be a function very similar to Mental Multiplication. There is the same rapid rise with no evidence that the function is nearing a practice level.

10. During this short period of practice none of these curves shows a plateau; some of the functions tested were of course too simple to furnish an opportunity for the formation of higher habits; others did not have sufficient exercise to permit of this. Lack of

[1] Thorndike, "Educational Psychology," II, 235.

interest would, moreover, hardly have been operative in an experiment where the social situation was stimulating the subjects toward continuous improvement.

TABLE XVI

COMPOSITE PRACTICE CURVES

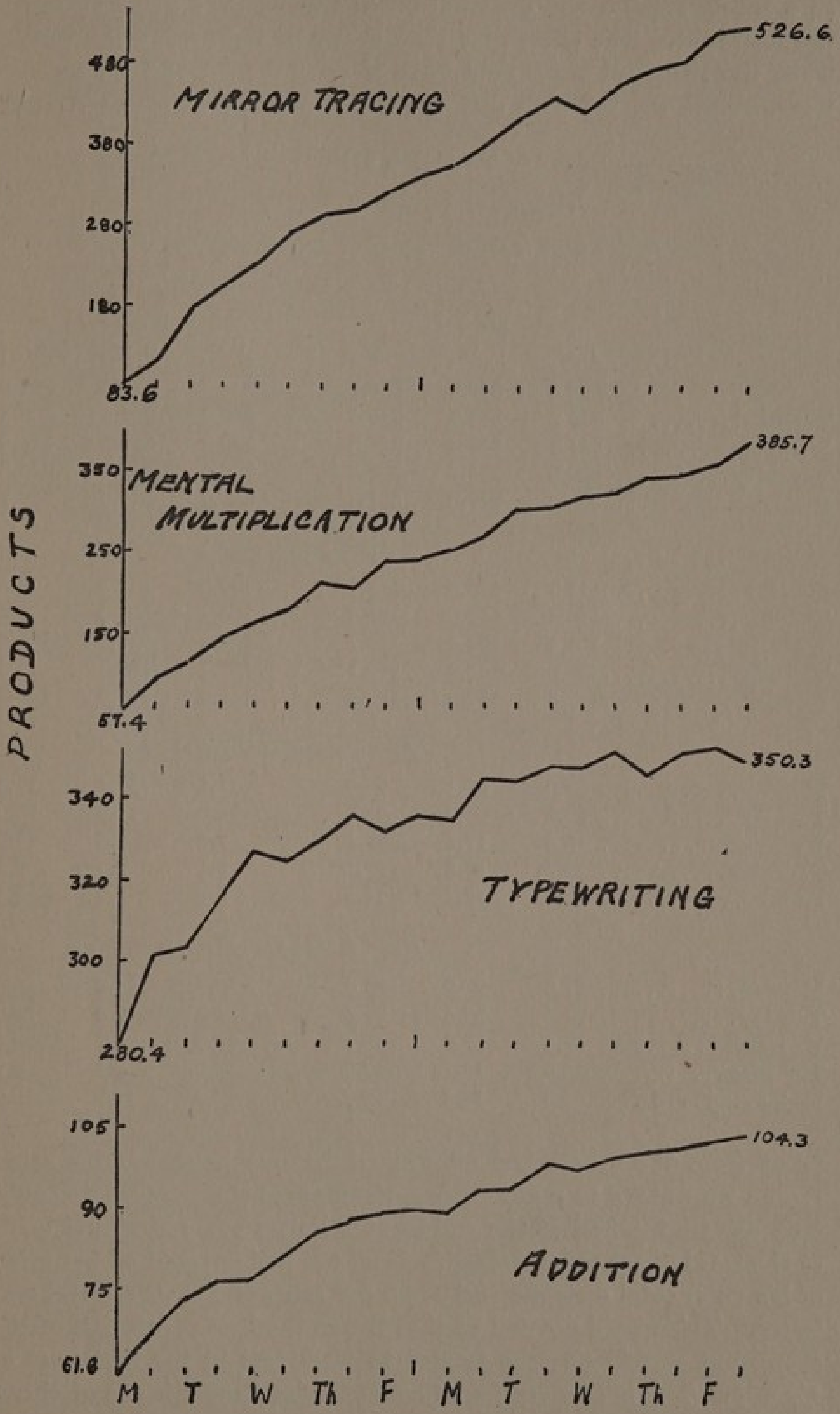
Each Figure is the Average of 22 Determinations[16]

	Week I		Week II	
	A.M.	*P.M.*	*A.M.*	*P.M.*
	Mirror Tracing (Net Score)			
Monday	83.6	124.7	358.3	387.6
Tuesday	180.6	215.9	414.8	437.6
Wednesday	237.1	269.7	421.0	458.5
Thursday	292.9	300.5	478.7	488.2
Friday	323.9	342.4	523.4	527.6
	Mental Multiplication (Net Score)			
Monday	57.4	93.3	254.4	271.8
Tuesday	118.6	143.3	302.9	308.8
Wednesday	165.5	182.2	320.9	325.0
Thursday	212.6	209.7	345.4	348.9
Friday	240.2	244.1	362.4	385.7
	Typewriting (Net Score)			
Monday	280.4	311.0	334.9	345.2
Tuesday	304.4	315.9	345.1	347.7
Wednesday	326.8	324.9	348.2	352.4
Thursday	329.5	335.8	346.5	351.9
Friday	332.4	335.9	352.9	350.3
	Addition (Net Score)			
Monday	61.6	66.5	88.8	93.6
Tuesday	73.0	76.9	94.2	96.7
Wednesday	79.9	81.7	96.0	98.9
Thursday	84.7	87.5	100.3	101.4
Friday	88.8	89.9	103.5	104.3

[16] Except in the case of Mental Multiplication when 21 were used.

The curves in the graphs so far presented are not exactly comparable in form, even within the same group of tests, because of the differences in the range of the various performances. In order to reduce each group of tests to the same scale the total ranges were equalized thus: For each test the total difference between the maximum and the minimum performance was taken to be 100 per cent. Then the difference between each point on the curve and the minimum performance was expressed in relation to the total difference between maximum and minimum score (or errors). That is, each point on Graphs III and IV represents the percentage of

GRAPH I


PRODUCTS
MIRROR TRACING
526.6
480
380
280
180
83.6
MENTAL MULTIPLICATION
385.7
350
250
150
57.4
TYPEWRITING
350.3
340
320
300
280.4
ADDITION
104.3
105
90
75
61.6
M T W Th F M T W Th F

the total improvement reached up to a given time and the graphs as a whole express the distribution of the practice gains through the fortnight. The curves for each group of tests represent somewhat the situation we should have if several men had set out to walk. Each started at a different point and ended at a different

TABLE XVII

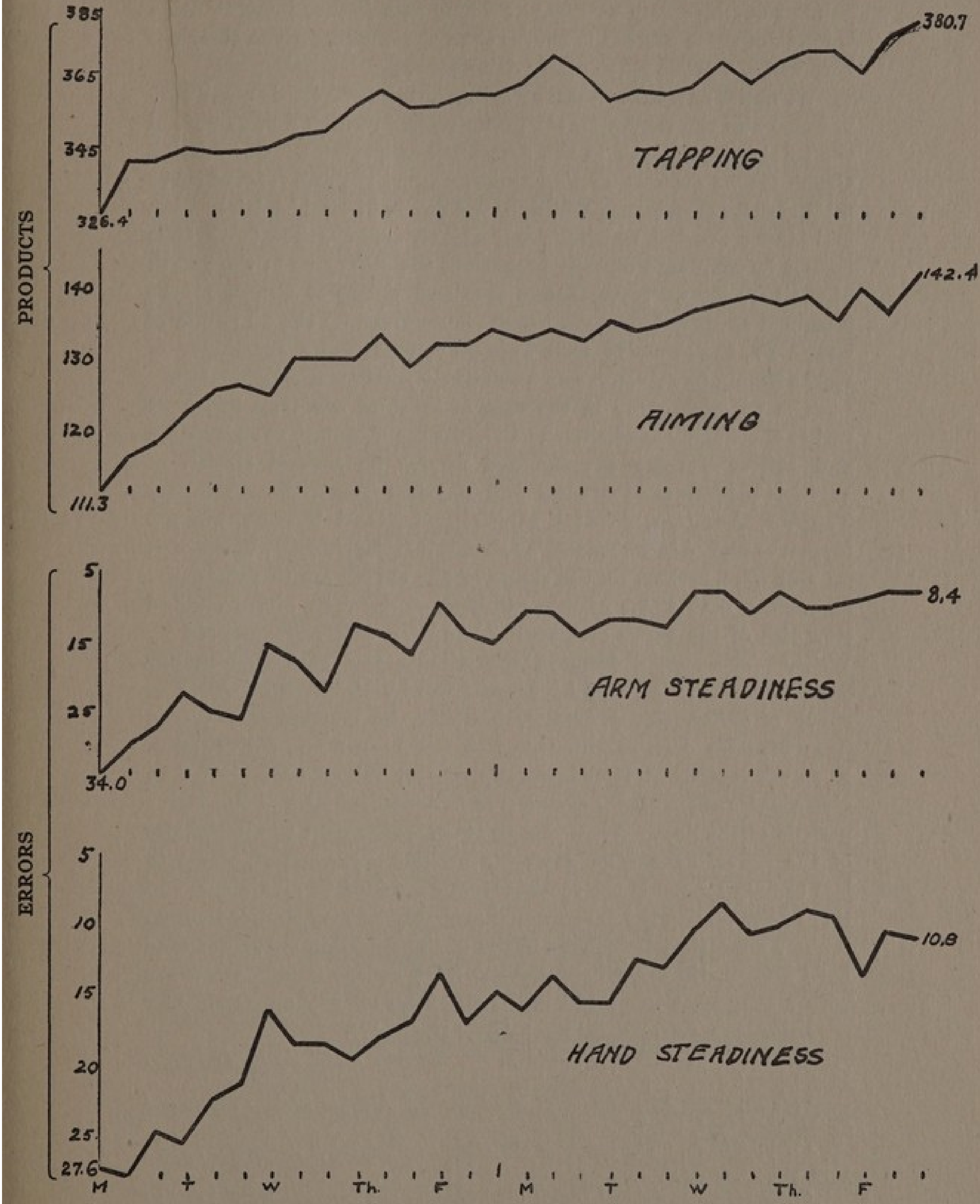
Composite Practice Curves

Each Figure is the Average of 22 Determinations.

	Week I			Week II		
	A.M.	*P.M.*$_{I}$	*P.M.*$_{II}$	*A.M.*	*P.M.*$_{I}$	*P.M.*$_{II}$
Tapping (Net Score)						
Monday	326.4	340.9	340.7	364.2	372.4	366.9
Tuesday	345.3	343.9	343.5	359.0	361.8	360.5
Wednesday	344.9	348.8	349.8	362.9	369.6	364.4
Thursday	356.6	361.5	356.5	369.5	372.8	372.6
Friday	358.0	361.0	361.3	367.2	377.0	380.7
Aiming (Net Score)						
Monday	111.3	115.6	118.1	132.8	134.4	133.3
Tuesday	122.4	125.0	125.8	135.4	134.0	135.2
Wednesday	125.4	129.5	129.7	136.9	138.1	139.0
Thursday	130.0	132.9	129.1	137.7	139.3	136.4
Friday	132.3	132.3	133.5	140.0	137.0	142.4
Arm Steadiness (Errors)						
Monday	34.0	30.1	26.9	11.1	11.4	14.3
Tuesday	23.1	25.0	25.6	12.0	11.6	13.0
Wednesday	15.6	17.7	21.7	7.7	7.6	11.3
Thursday	12.7	14.3	17.1	8.1	9.5	9.5
Friday	10.0	13.5	14.8	8.7	8.2	8.4
Hand Steadiness (Errors)						
Monday	27.6	28.2	24.9	15.8	14.0	15.5
Tuesday	25.4	22.5	21.4	15.3	12.5	13.2
Wednesday	16.4	18.6	18.7	10.6	8.7	10.5
Thursday	19.5	18.2	17.2	10.0	9.1	9.7
Friday	13.3	16.8	15.2	13.6	10.7	10.8

point from the others but all walked for one hour. If for some reason we wanted to make their performances comparable we could only say that A had at the end of 15 minutes covered 10 per cent. of the total distance he walked, whereas B had covered 40 per cent. of his (B's) total distance and C 20 per cent. of his (C's) total distance. This would not tell us that B was the best pedestrian of the group but merely that he tended to walk fast in the first part of his trip. The misconceptions that can arise from the use of either

Graph II


PRODUCTS
ERRORS
385
365
345
326.4
380.7
TAPPING
140
130
120
111.3
142.4
AIMING
5
15
25
34.0
8.4
ARM STEADINESS
5
10
15
20
25
27.6
10.8
HAND STEADINESS
M
T
W
Th.
F
M
T
W
Th.
F

absolute or relative gain as a criterion of practice effect have been pointed out by many writers.[2] So long as no other interpretation is made of these percentile curves than the one just given their use here will not prove particularly dangerous.

We notice now that Graph IV brings out the previously noted convex shape of the curves for the motor tests, in which a large part of the total gain is made in the first week of practice. Considering Graph III we see that Typewriting resembles the first form of curve most closely; then comes Addition, and finally Mental Multiplication and Mirror Tracing, which are only slightly convex. The two graphs cannot be compared directly because of the difference in the length of the base lines. Nevertheless if the 20 points of Graph III be imagined as spread out over the space occupied by the 30 points of Graph IV, the group of tests appears to represent a continuity of stages from a fairly convex to a relatively rectilinear relationship.

The practice curve in the case of most of our tests has been rather thoroughly studied. The results for Tapping, Computation and Mirror Tracing are summed up in the revised edition of Whipple's Manual of Mental and Physical Tests; the results for Tapping, Addition, Mental Multiplication and Typewriting are further analyzed in Thorndike's Educational Psychology, Volume II.

Our observations on the shape of the curves are in substantial agreement with those of other investigators. The often-reported slow rise of the curve of Tapping has been carefully analyzed by Wells.[3] The special form of the Aiming test employed in our experiment was also used by Marsh[4] and by Hollingworth.[5] The curve of improvement cannot, however, be conveniently traced from Marsh's data as compensation has been made for practice. Even the records of Hollingworth's control subjects are plotted to give a series of curves for each one of five performances at successive periods of the day. According to this arrangement the initial rise of the curve, even after a week's preliminary practice, seems to last unduly long. If the records were combined to give a curve of three points a day the curve would probably be very similar to ours.

The characteristic convex shape of the Addition curve has long been known, though Chapman[6] got from college students a curve with a somewhat less rapid initial rise than usually appears. Our

[2] Thorndike, "Educational Psychology," II, 165–177.

[3] Wells, "Normal Performances in the Tapping Test," *Amer. J. Psych.*, 1908, 19, 437.

[4] Marsh, "The Diurnal Course of Efficiency," *Archives Philos., Psych. and Sc. Methods*, 1906, No. 7.

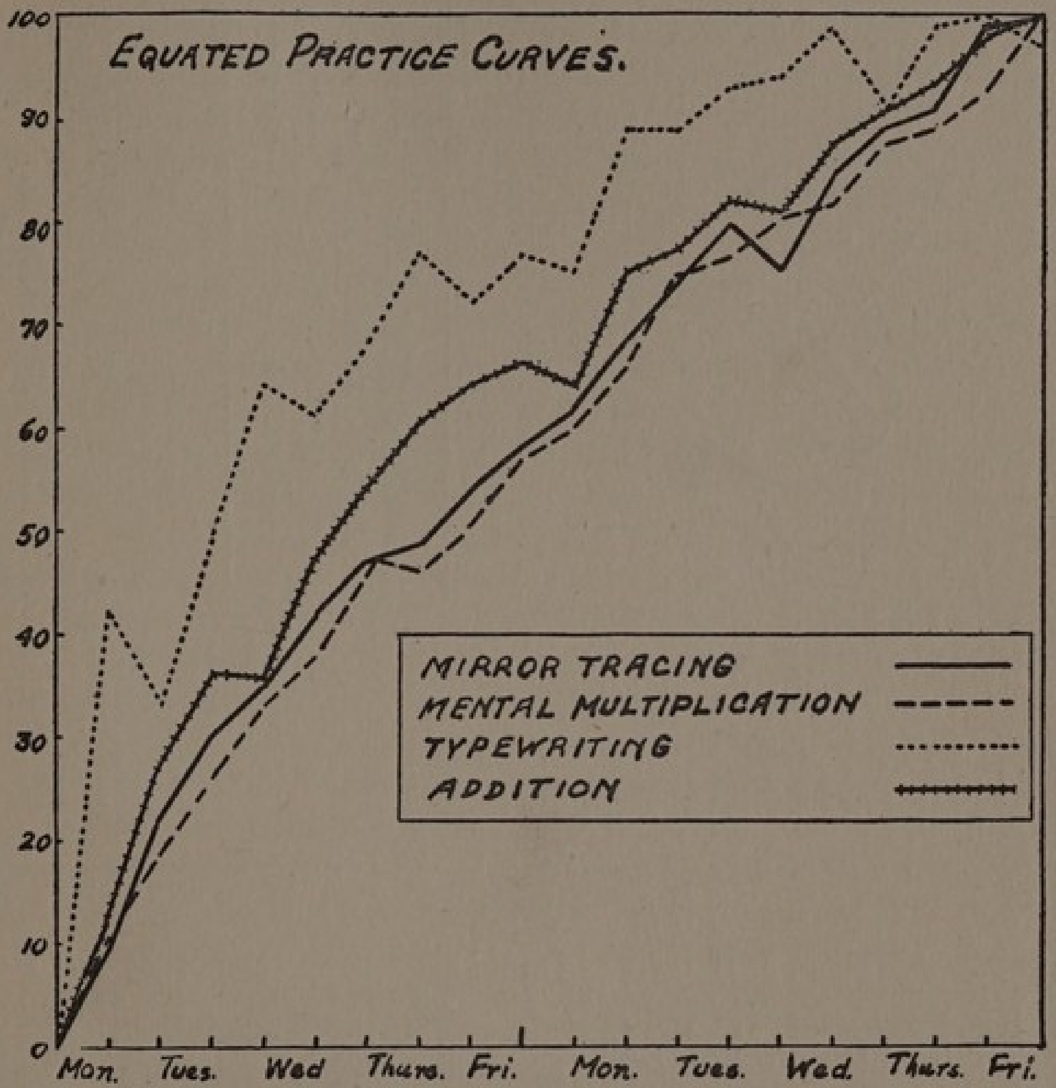
[5] Hollingworth, "The Influence of Caffein on Efficiency," *Archives of Psych.*, 1912, No. 22.

[6] Chapman, "Individual Differences in Ability and Improvement," *Teachers College, Columbia University, Contributions to Education*, 1914, No. 63.

curve for Addition, like Chapman's, shows no sign of flattening at the end such as has been found by Wells[7] with nurses and Thorndike[8] with school children. (Figs. p. 237 and p. 254, "Ed. Psych.," Vol. II.)

Our curve for Typewriting in a general way resembles curves given by Book,[9] although our subjects started with a considerable

GRAPH III



(unknown) amount of practice which brought them to a practice level earlier than was the case with Book's subjects.

Our steep curve for Mirror Tracing corresponds to about one quarter of the long practice curve in which Starch[10] found a later

[7] Wells, "The Relation of Practice to Individual Differences," *Amer. J. Psych.*, 1912, 23, 75.

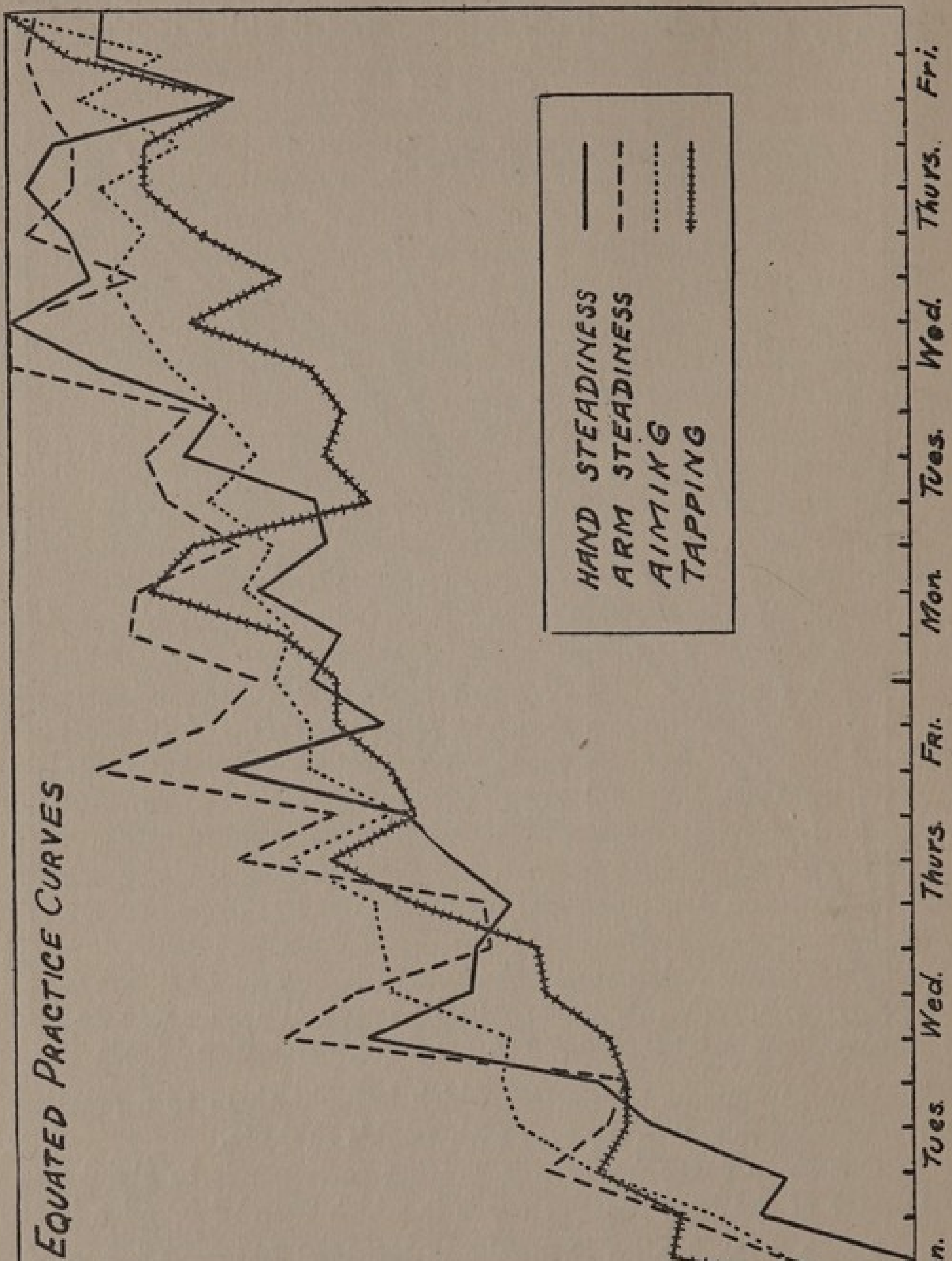
[8] Thorndike, "Practice in the Case of Addition," *Amer. J. Psych.*, 1910, 21, 483.

[9] Book, "The Psychology of Skill: with Special Reference to Its Acquisition in Typewriting," *University of Montana Publications in Psychology: Bulletin No. 53, Psychological Series No. 1.*

[10] Starch, "A Demonstration of the Trial and Error Method of Learning," *Psychological Bulletin*, 1910, 7, 20.

slowing up, with maximum efficiency only after about 90 tracings of the star.

Graph IV



There appears to be no published account of the effect of long practice on the Hand Steadiness test. Such data exist in Hollingworth's records, but no comparison can be made at this time. An unpublished essay by Meylan also contains an account of a long practice series at the end of which subjects were able to hold the hand steady for several minutes without making any touches.

II. *Variations in Efficiency During the Working Day*

The previously noted variability in the motor performances lead us to inquire into the question as to whether these variations occurred with sufficient regularity to be taken as evidence for real fluctuations in efficiency during the course of the day's work. Our data, while totally inadequate for establishing the diurnal course of efficiency, did supply as an interesting by-product a certain amount of information about the relative effects of fatigue and practice under well-standardized conditions.

An examination of the foregoing tables and graphs shows that although in the group of more intellectual tests the subjects were making almost uninterrupted improvement throughout the two weeks, in the more simple sensori-motor tests, which were given three times a day, the subjects were nearing a practice level. A closer inspection of these curves in the second week of their course reveals the following facts:

Tapping.—While the P.M.$_{I}$ performance is on every one of the five days better than the A.M. performance, the P.M.$_{II}$ though better than the A.M. is worse than the P.M.$_{I}$ performance on four days. A considerable end-spurt on the last day of the experiment masks any fatigue that might naturally have occurred.

Aiming.—The matter is not very clear here. Three out of the five P.M.$_{I}$'s are better than the A.M.'s, and three out of the P.M.$_{II}$'s are better than the P.M.$_{I}$'s. The improvement of the P.M.$_{II}$ over A.M. is clear in only three cases. This vague tendency to improvement makes it seem unlikely that fatigue is strongly operative. It is perhaps significant that on Friday when the subjects started with a high score in the A.M. their score came down at P.M.$_{II}$ and went up again in a considerable end-spurt.

Arm Steadiness.—Three out of the five days show a better performance at P.M.$_{I}$ than at A.M., and four out of five days a worse performance at P.M.$_{II}$ than at P.M.$_{I}$, the fifth day being equal (which really means diminished efficiency because of failure to improve). In every case but Friday, where end spurt may be operative, the last performance of the day is worse than the first performance.

Hand Steadiness.—Every P.M.$_{I}$ is better than the A.M., and every P.M.$_{II}$ is worse than the P.M.$_{I}$, though better than the A.M. performance.

In order to study these differences further, a three-point curve was arranged for each of the four tests, *i. e.*, all of the second week data for all subjects was averaged for an A.M., a $P.M._{I}$, and a $P.M._{II}$ point (about 110 determinations for each point). Table XVIII presents these curves.

TABLE XVIII

VARIATIONS IN EFFICIENCY IN SECOND WEEK

Each Figure in the Average of 110 Determinations[11]

	A.M.	$P.M._{I}$	$P.M._{II}$
Tapping (Score)	364.54	370.80	369.02
Aiming (Score)	156.56	136.60	137.23
Arm Steadiness (Errors)	9.52	9.65	11.32
Hand Steadiness (Errors)	13.08	10.95	11.94

Considering the variations as brought out by these figures, we find that:

For Tapping, this method corroborates the findings of the day-method. Tapping starts low at A.M., and goes up at $P.M._{I}$, and comes down again at $P.M._{II}$, though not to the level of the A.M. performance.

For Aiming, this method agrees with the day-method in showing a slight improvement throughout the day.

For Arm Steadiness, this method agrees with the day-method in showing deterioration at the end of the day, but without the improvement in the middle of the day.

For Hand Steadiness, this method again strengthens the differences found by the day-method. The performance is worst at A.M., much better at $P.M._{I}$ and slightly worse at $P.M._{II}$.

It is obvious that such small differences as those found by either of these methods would fall well within the probable error of the average. The results are, moreover, still complicated by practice. They have therefore small validity of themselves, but are to be considered as corroborative of certain general tendencies traced by previous workers along the line of diurnal variations.

As early as 1892, Dresslar[12] found evidence of a diurnal rhythm in tapping, with a minimum at 8 A.M. and a maximum at 4 P.M. Marsh[13] has summed up the earlier work and added data on a variety of functions. In regard to his group of coordination tests requiring accuracy and speed of movement (Striking squares,

[11] A.M. figures are the average of 109 determinations.

[12] Dresslar, "Some Influences Which Affect the Rapidity of Voluntary Movements," *Amer. J. of Psychology*, 1892, 4, 514.

[13] Marsh, "The Diurnal Course of Efficiency," *Archives of Philos., Psych. and Sc. Methods*, 1906, No. 7.

Snapping, Three Hole Aiming, Tapping) his conclusions are: "The thing most worthy of note . . . is the exceptional occurrence and decisiveness of the maximum tapping rate at 9–10 P.M. . . . The maximum of accuracy comes earlier in the day than the maximum of speed . . . ; there is no doubt that it falls somewhere in the middle portion of the day. . . . Tapping also gives a different diurnal course from other tests of speed, such as striking squares or writing numerals. In explanation of this difference it is suggested that rapidity of tapping, as it requires a minimum of control but a maximum of neural excitement, may be expressive largely of nervousness. If a person is most nervous in the evening, he would accordingly be quickest in tapping at that time, but not most accurate in motor control." Hollingworth,[14] working with Tapping, Three Hole Aiming, and Typewriting, found similarly that "mere speed showed a maximum at the end of the day, and speed with accuracy prescribed (Aiming) at the middle of the day." Hollingworth also found a general increase in Steadiness throughout the day, which is hard to reconcile with Marsh's theory that rapidity of tapping is indicative of nervousness, increasing as the day goes on.

In comparing these results with our own, it must be remembered that our working day was really only half a day; Marsh and Hollingworth gave records for test periods up to after 10 o'clock P.M. The time at which each of our three tests came was roughly:

	A.M.	*P.M.*$_{I}$	*P.M.*$_{II}$
Aiming	9:30	1:45	4:10
Hand Steadiness	"	"	"
Tapping	"	"	"
Arm Steadiness	10:15	2:15	4:15

Gates[15] has recently tested school children and college students with a number of tests (sensory motor, association, memory, etc.) and found evidence of a broad type of diurnal fluctuation in efficiency. According to him there is a steady rise from morning to midday. In the afternoon the motor processes continue to increase in efficiency while more strictly mental functions show an after-lunch decrease followed by a final increase in efficiency.

A brief comparison of some of our results with those of Hollingworth shows certain similarities. We found that Tapping starts

[14] Hollingworth, "Variations in Efficiency During the Working Day," *Psych. Review*, 1914, 21, 473.

[15] Gates, "Variations in Efficiency During the Day, Together with Practise Effects, Sex Differences and Correlations," *University of California Publications in Psychology*, 1916, 2, 1. Gates, "Diurnal Variations in Memory and Association," *University of California Publications in Psychology*, 1916, 1, 323.

low, goes up in the middle period and then comes down again. Hollingworth found Tapping to be rather a variable function as is shown by the following table of average time taken for 400 taps:

Time of Day	10:30	11:15	12:00	1:30	2:15	3:00	3:45	4:15
Av.	49.8	49.2	47.8	47.7	48.0	48.3	47.2	47.9

It is possible that we both struck a point of increased efficiency at about 1:30 and a point of somewhat less efficiency about 4:15. We agree in finding improvement from A.M. to P.M. In regard to Hand Steadiness our records show a general improvement during the day, with a point of greater efficiency at 1:30 and a point of less efficiency at 4:15. Hollingworth's table for average number of contacts is:

Time of Day	10:30	11:15	12:00	1:30	2:15	3:00	3:45	4:15
Av.	15.0	15.0	14.6	12.0	14.2	14.2	13.8	12.7

It happens that as in our own results the 1:30 determination is again the best point on this part of the curve, and that the rise in efficiency which characterizes the latter part of the day has not gone very far by 4:15. The discrepancy between our course for Aiming (gradual improvement throughout the day) and Marsh's and Hollingworth's (maximum efficiency at Noon) is probably due to the persistence of practice in our experiment. A comparison of mental tests (which Hollingworth finds decrease in efficiency as the day goes on) and motor tests (which Hollingworth finds increase) is not possible from our study because of the practice effect. For the same reason our results for Mental Multiplication cannot be compared with those of Thorndike and Arai. In general our results should not be taken too seriously, as reliable information on the matter of such variations can only be obtained from a long series of tests in which many points on the day's curve are established.

CHAPTER VII

THE TESTS IN THE LIGHT OF EXPERIMENTAL EVIDENCE

CERTAIN general observations about the tests made by the experimenter or by the subjects themselves, as well as quantitative information more extensively reported in previous chapters may here be treated. In regard to the Addition test, it was interesting to see how much individuals who had had far more than an ordinary amount of practice improved as the result of a few minutes a day of intensive work under conditions of enthusiastic rivalry and interest in improving upon each day's record. The subjects approved the use of the two-minute work intervals and felt that they were stimulated by having their progress thus brought to mind. As the test has quite a high inter-group or reliability coefficient (.96) with the number of determinations made, an individual was pretty accurately measured.

The Three Hole Aiming test, performance in which had often seemed to the experimenter to vary rather unaccountably, nevertheless gave a fairly good coefficient of reliability (.93). The test measures speed, principally, except in so far as inaccuracy in not hitting the target directly, but sliding over toward the hole, increases the time taken for each hit. The correlation between Aiming and Tapping seems logical on the basis of a common speed element; but the lack of correlation with Typewriting, into which the same factors of speed and accuracy apparently enter, is quite unintelligible, especially in view of the fact that Hollingworth found Aiming and Typewriting to be similarly affected by caffein.

Tapping is a test peculiarly subject to end-spurt and other variations because of change in interest, rivalry, and so on. Our subjects regarded this test (and also Aiming) as a sort of race, with the sight of the counterhands moving around the dial, and the noise of the other subject's performance, acting as a spur to further achievement. During the first day the subjects sometimes had trouble in adjusting the height and the force of the tapping so as to insure the instrument's recording every tap, but soon overcame this difficulty. Notwithstanding the necessity of using this rather crude method of recording, the performance seems to have been as satisfactorily measured as in the case of Addition. The superiority of the $P.M._{I}$ over the $P.M._{II}$, if indeed it is a true one, could hardly be explained on the basis of interest, as enthusiasm for improvement was usually greatest at the "last-chance-for-the-day" trial.

The electric-counter method employed in the Steadiness tests gave a consistent measure of ability (.98 for Hand, .99 for Arm Steadiness) and was satisfactory for comparative purposes in the ventilation study. For an absolute measure of the degree of unsteadiness one would have to resort to greater refinements of method. In the Hand Steadiness test we found one or two individuals with a hand tremor so light and so rapid that the apparatus did not measure it accurately. In the Arm Steadiness test the hole was somewhat too large for very light touches to be recorded; yet the size could not be decreased much, because a constant noise of the counter recording errors would have thrown the subjects into utter confusion. The two tests, as we used them, do measure rather different things, which somewhat accounts for the indifferent correlation found.

In the Hand Steadiness test the subject was comfortably seated and had to control a rather small set of muscles to avoid movement in a horizontal plane. Irregularities in breathing, an eye movement, a start at the sound of the other subject's counter, or even a faint desire to laugh, resulting from the general strained situation, had a disastrous effect on the record. Since this was demonstrated to the subjects on the preliminary day, they were generally very cooperative in obtaining a true measurement.

The Arm Steadiness test seems to be more of the nature of a fatigue test. In the first place the subject was tested standing, and for two minutes rather than one, as in the Hand Steadiness. Then she held a long pointer which seemed very heavy before the end of the two minutes. There was, moreover, considerable eye-strain and adaptation during the course of the test so that the visual guide became less helpful, and the swayings of the whole body, as well as gross arm-movements, were recorded. This was shown in the appearance of circular movements of the arm, during which the tip of the pointer made a series of touches around a large portion of the hole. The test also measured movements in the sagittal as well as in the vertical plane. This differentiation between the two tests does not, however, hold in the correlations with other tests, as we have noted before.

The net score for our practiced subjects in Typewriting was quite constant (reliability .99). The relation between errors and speed has not as yet been worked out, but the records give one the impression that those who write fast also make many errors. Of course touch-writers are peculiarly liable to make errors unless they are very expert indeed. Here it must be said that the errors were mostly due to lack of fine adjustments in manipulating the machine, such as striking letters too close together, spacing in the wrong place, writing capital letters above or below the line, and shifting the entire hand out of its proper position on the keyboard. Other errors were of a more intellectual order, such as doubling letters, associating the proper finger with a letter but using the wrong hand, skipping, repeating, interchanging letters within a word, and forgetting to end a line as in the copy. Practically all the errors noted by Wells[1] in his fine analysis of the psychomotor mechanisms of typewriting occurred in our records. No more than 10 was ever subtracted for errors within the same line. Possibly the fast writers were unduly penalized in the use of a machine without a "back spacer." At any rate, the subjects were more interested in speed than in accuracy and the conditions of the test (four subjects typing at once) were rather conducive to haste.

The Mirror Tracing device, though requiring a good deal of care and polishing, was very satisfactory, as the slightest break of contact warned the subject of an error and produced an immediate corrective movement. Large excursions from the track never occurred. The small excursions might have been measured more accurately with a narrower strip and finer stylus, but it is doubtful whether the counter would have worked for a very much briefer break in the circuit. The reliability of the test is .96. A certain amount of variability in the performance resulted from conflicting ideals of speed and accuracy. To overcome this, the subjects were instructed to work for accuracy rather than speed, and were heavily penalized for errors. The test shows a negative correlation with Aiming, but resembles the other motor tests and also the intellectual tests. The use of the time-limit form of this test, in which several tracings can be made, seems a useful variation in technique for a long practice experiment since it allows the new habit to improve more steadily, permits of indefinite improvement and gives opportunity for a study of errors as fatigue progresses.

The extraordinarily low reliability of the Industrial Fatigue test (.24) may possibly be explained on the basis of variations in the speed of the rotating arm. It seems more likely, however, that in one trial a subject, having gone on for some time in an automatic manner, becomes careless, loses control of herself, and makes a large number of errors in her confusion, whereas in another trial by just a little more care she insures a perfect record. The subjects

[1] Wells, "On the Psychomotor Mechanisms of Typewriting," *Amer. J. Psych.*, 1916, 27, 47.

all complained of the monotony of the task and the accompanying eye-strain. Though the test is so largely influenced by chance, its correlations with all the motor tests but Aiming seem to be positive. With Wink and Tremor it is negative.

Our use of the Mental Multiplication test gave but little new information. No attempt was made to prescribe a standardized method of doing the work but all methods were taught, and the subjects were allowed to use short cuts. In a way this is less desirable than having all the work done by the addition-of-partial-products method; still, unless one has subjects with an extraordinary amount of scientific conscience there is no guarantee that the work is being carried out by a harder method when a quicker one has suggested itself to a bright subject. A very satisfactory inter-group correlation resulted from this method (.99).

Considering now the Reflex Wink test, we found great individual differences in native capacity. Some subjects always winked when the hammer hit the glass, some never winked throughout the experiment, and some gradually ceased winking. Just what is the significance of the fact that a subject does not wink when nature intended that she should, is hard to tell. It may mean superior control, and it may mean greater insensitivity. As far as the ventilation experiment goes, this reaction does not seem to change under the air conditions studied. Partridge[2] found what he called "improvement in control" under the influence of alcohol, though this might equally well be called lessened sensitivity. He also found a gradual improvement in control in school children with increasing age. Swift[3] likewise found that a six months old baby did not wink, whereas it did begin to wink before ten months. All this seems to point to the possibility that the cessation of the reaction may be an undesirable thing, as is the diminution of the knee-jerk. Perhaps it would be better to change the sign of correlations with the Wink. At least this possibility must be borne in mind in interpreting our data. Whatever is being measured is definitely characteristic of the individual for the reliability is .99.

In regard to the observation of Eyelid Tremor, the experimenter felt that it was hardly worth while to use the five-point scale as only the extremes could be judged with any certainty. Individuals seemed to vary considerably on the middle of the scale and almost all, during the course of the experiment, showed improvement in

[2] Partridge, "Experiments Upon the Control of the Reflex Wink," *Amer. J. Psych.*, 1899–1900, 11, 244.

[3] Swift, "On the Origin and Control of the Reflex Wink," *Amer. J. Psych.*, 1903, 14, 230.

keeping the eyelids from flickering. The reliability is lower than in the other tests (.90). The absence of tremor seems to be associated with a steady hand, speed in tapping and failure to react with a protective wink. As a general index of any but pronounced nervous disorder it has little value.

CHAPTER VIII

Summary and Conclusions

The information obtained about Correlations, Practice and Diurnal Variations can not very conveniently be treated in a brief summary. This chapter will accordingly deal only with the main problem of the experiment. This study was undertaken primarily to investigate the supposed effect of air of low relative humidity upon nervousness as shown by defective motor control, and upon general inefficiency in work similar to that performed in daily life by clerks in offices and operatives in factories. Since tests can not be given often enough to obtain reliable measures of a changing condition without having the influence of the variables obscured by practice, the following device was adopted to balance out the practice effect. Subjects were tested in squads for a fortnight each. The first squad spent its first week under the wet, its second under the dry condition. The second squad spent its first week under the dry, its second week under the wet condition. For each test an average for performance in the wet weeks was obtained by adding the first week of Squad A and the second week of Squad B. A similar average for the dry weeks was obtained by adding the remaining weeks. By averaging the data from a number of squads, half of which were at the beginning, and half at the end of their practice curve, the practice was pretty well eliminated. Any remaining difference between the wet and dry averages might then be attributed to the ventilation condition.

Tests of:

Addition	Arm Steadiness
Aiming	Mirror Tracing
Hand Steadiness	Industrial Fatigue
Tapping	Reflex Wink
Typewriting	Eyelid Tremor

were given twice or three times a day in accordance with a fixed schedule, with 75° F., 50 per cent. relative humidity, and 75° F., 20 per cent. relative humidity as the air variables. In all of these tests the average performance computed as described above, and also the average improvement from the first to the last trials on any particular day, showed no reliable difference. That is, by these tests of nervous and motor control and by the more purely intellectual tests we could detect no influence of excessive dryness during two weeks' exposure or during the working day. While the physiologist would hardly expect any profound nervous deterioration from eight hours' or even two weeks' exposure, the advocates of high relative humidity in schools, offices, and other buildings claim to be able to detect the deleterious effect of dry air in even shorter time. The practical situation is that experimental humidity conditions considerably more rigorous than those obtaining in any artificially heated apartment show no demonstrable effect in behavior. Similarly, wherever psychological tests have been used in ventilation studies, the results have been negative.

Whether or not the subjects all put forth the same amount of energy or approached their maximum of effort matters little. The fact is that working quite naturally at what they regarded as a pleasant and not too strenuous job, they worked no less efficiently and showed no poorer control under excessively dry than under more favorable conditions. The argument that subjects are able by exerting extra effort to overcome uncomfortable conditions would not apply to the humidity experiment since the subjects did not feel uncomfortable, as is shown by their comfort votes. Moreover, any real physiological disturbance not reflected in the subjective feeling of comfort must have been detected in the objective determinations of pulse and temperature, which again gave negative results.

Still, our finding that individuals put under certain controlled conditions react or fail to react in certain ways is by no means to be taken as sanction for all sorts of uncomfortable ventilation conditions. It must be remembered that in isolating the factor of humidity, we did not attempt to reproduce the conditions that go to make up a crowded, ill-smelling and excessively hot room. The very fact that the method of ventilating the experimental chamber produced a normal amount of air movement tended to alleviate the discomfort that would ordinarily be felt in a closed room under a 75°, 20 per cent. condition. Nevertheless, previous experiments by the Commission have shown that behavior or product per unit of time is not affected by even more rigorous combinations of conditions. Whether this is due to a real absence of harmful effects, or to the marvellous power of the human organism to adapt itself to a changed environment, is at present still a matter of speculation. Psychology has given its answer, as far as it can in the present state of the science, to the question as to whether the ventilation conditions commonly found, have any effect on the practical activities of life. If this absence of demonstrable effect is due to a constant adjustment of the organism that will eventually result in strain, it is for physiology to trace any subtle, long-time ill-effects that may have escaped the behavior tests.

APPENDIX

Instructions to Subjects

I. *Directions for Addition Test*

You will be given (Printed side down) several sheets like this one.[1]

1

2	3	3	9	4	9	3	2	9	8	7	6	7	5	6	9
5	5	7	2	2	3	7	5	4	7	9	2	5	9	2	4
8	7	3	7	3	6	8	6	4	4	6	9	2	5	7	7
8	2	8	8	2	6	5	8	7	9	4	6	7	6	5	8
7	6	2	2	9	5	3	3	6	4	9	5	5	8	2	8
7	8	6	4	5	8	2	8	5	8	7	6	8	2	9	2
2	7	9	5	8	4	8	8	9	4	5	3	6	9	8	9
9	9	3	7	7	8	3	7	4	7	9	5	4	7	4	2
6	4	6	4	5	3	9	3	4	9	8	9	8	7	2	7
9	9	8	9	5	2	8	8	8	7	6	7	3	3	7	6

2	4	9	5	8	2	9	6	3	6	7	8	4	4	5	4
9	6	9	9	2	7	3	6	9	7	5	6	8	6	7	7
6	5	8	4	8	9	3	7	8	9	9	3	3	3	9	4
3	4	6	8	9	7	8	4	7	5	2	6	9	5	2	5
7	9	9	2	4	2	4	4	3	7	5	9	6	8	4	7
2	2	8	9	6	9	2	5	2	6	3	5	2	3	8	6
9	7	6	6	2	6	6	4	3	4	4	2	4	5	3	9
6	2	3	3	7	3	9	7	4	5	8	9	9	6	9	8
3	9	2	8	9	5	5	9	7	4	9	7	2	2	8	9
8	5	6	4	5	7	6	6	9	9	9	2	8	6	2	4

5	6	4	7	8	2	7	8	6	7	8	7	7	2	3	5
8	5	7	3	4	6	4	6	7	4	7	5	8	7	8	7
3	8	5	8	2	3	6	3	6	8	5	8	6	9	5	6
6	7	9	5	5	8	9	8	3	3	8	7	5	4	7	8
4	7	6	3	9	3	7	4	9	3	9	2	6	4	9	6
7	4	8	6	7	9	8	5	6	7	2	8	5	6	4	3
6	9	5	6	5	9	3	7	8	5	6	9	3	6	4	3
5	8	8	7	9	5	4	4	2	7	9	2	5	3	8	7
9	3	3	6	2	2	5	9	4	8	4	6	7	5	9	5
6	6	2	9	3	5	4	3	7	5	3	8	7	8	6	4

At the word "Ready" catch hold of the lower left-hand corner of the whole pile of sheets with your left hand, and take your pencil in your right hand. At the word "Go" turn over your sheets from

[1] The type here differs in size and form from the original.

the bottom, away from you. This will bring the sheets right side up. Beginning at the left-hand column of the upper row add these figures. Write the sum of each column of 10 figures as fast as you can, but without making errors. If any answer is wrong you will receive no credit for the answer in that column, but do not stop to verify or check up your answers. When you have finished one sheet go on to the next, putting the sheet you have just finished upside down before you. Work as fast and as accurately as you can until you hear the word "Mark." Then make a slanting line just where you are, and go on quickly with your adding. Do not let the sound of the word "Mark" cause you to forget the partial result you had in mind. Even if you are in the middle of a column make that mark where you are. I will say "Mark" every two minutes. When you hear the word "Stop," stop right off, turn over your sheets, write your letter and the date on every sheet you used. I want to find out how many sums you can do correctly in 10 minutes.

II. *Directions for Aiming Test*

The apparatus for this test is the inclined triangle at the left of the board. Take the stylus in your right hand, put your left hand on the board to hold it down and sit directly in front of the board. At the signal "Ready" hold the stylus point just above the upper hole and at the word "Go" put the stylus as rapidly as possible down into the bottom of the holes, one after the other, going around the triangle clockwise. As I say the word "Go" I will turn on the electric current, and after that every contact of your stylus with the metal at the bottom of the hole will ring up one hit on the counter. I want to see how many hits you can ring up in one minute, so I will turn off the current again after one minute and will then say "Stop." Keep on working hard until you hear that word. Keep your eyes on the work you are doing so you will be sure to get the stylus accurately in the hole. Do not watch the counter or your neighbor.

III. *Directions for Hand Steadiness Test*

The apparatus for this test is the inclined block at the right of the board. Take the stylus in your right hand, put your left hand behind you and sit in front of the block. At the signal "Ready" insert the point of the stylus a little way into the hole I will indicate to you. Hold the stylus like a pencil, and bend your arm as though you were going to write. Do not support your hand or arm in any way. Hold the stylus perpendicular to the plane of the block. Try to hold the stylus so steady that it will not touch the sides of the hole. At the word "Go" I will throw in the switch for the electricity. After that, every time you let the stylus touch the metal, you will hear the counter record one error. Try to make very few errors. At the end of one minute I will turn off the current. The test will be over when you hear me say "Stop."

IV. *Directions for Tapping Test*

The apparatus for this test is the brass plate in the center of the board. Sit down in front of the board with the right wrist through the tape binder and resting on the table lower than the board. Be sure to keep the wrist down on the table during the entire test. At the word "Ready" take the stylus in your right hand like a pencil. At the signal "Go" tap the metal plate with the stylus just as fast as possible. After three taps I will throw in the switch and you will see the counter working. Keep your eyes on the counter and tap hard enough to make each contact ring up on the counter. At the end of one minute I will turn off the current and then say "Stop." Try to see how many taps you can make in one minute.

V. *Directions for Typewriting Test*

Be sure that you are thoroughly familiar with the machine you are to use. Use only one method of typewriting throughout all the work you do here. In this test as in all others you are to work as fast as possible but without making mistakes. If, however, you do make a mistake do not go back to correct it, but continue copying. The material for you to copy is in these red books. (Thorndike, "Principles of Teaching"). Never copy headings at the top of the pages but copy such headings as occur in heavy type at the beginnings of paragraphs. Always begin work at the indentation of a paragraph which is marked with a number, and continue copying until you reach a place that is marked with a long line drawn horizontally across the page. Skip from that point to the next indentation of a paragraph which is marked with a number. At the word "Ready" you should be in position at the typewriter with your paper inserted and your copy open to the place you are to begin at. Keep your place from day to day but never begin a new test in the middle of a paragraph; instead go on to the next new paragraph. Never do over again a selection you have once copied in a test. Your score will be 10 for each line done with 1 taken off for each wrong letter or wrong space or wrong punctuation and 2 taken off for more serious errors. I will clap my hands twice as a signal for you to stop. When I do this stop at once without writing another letter. You will be given a few minutes to look over your papers at the end of each test.

VI. *Directions for Arm Steadiness Test*

The apparatus for this test is the block screwed on the wall. At the word "Ready" take the pointer in your right hand and with the finger-tips just touching the black line take your distance from the hole in the block. With the pointer held at arm's length and shoulder height, you should get the brass tip of the pointer just within the hole. Keep your eyes fixed on the hole. At the word "Go" I will throw in the switch and after that, every time your pointer-tip touches the sides of the hole or the metal at the back, the counter will ring up one error. If I see that you are getting the pointer too far forward so that there is danger of your pulling it out of the hole I will say "In." After two minutes I will turn off the current and say "Stop." Try to hold the pointer so steady that you will make very few errors.

VII. *Directions for the Mirror Tracing Test*

Take the stylus in your right hand and place your hand under the screen directly over the star. Fix the screen so that you can not see your hand directly but only by reflection in the mirror. At the signal "Ready" place the stylus exactly in the center of the strip forming the upper point of the star and at the word "Go"

VIII. *Directions for Mental Multiplication Test*

You will be given a number of sheets like this:[2]

New York Ventilation Commission

Name Date

						(1)	(2)	(3)	(4)	(5)
A.	Began	No. 1, hr.	min.	sec.		437	695	839	548	974
	Finished	No. 5, hr.	min.	sec.		93	73	43	63	34
						(1)	(2)	(3)	(4)	(5)
B.	Began	No. 1, hr.	min.	sec.		948	456	679	873	389
	Finished	No. 5, hr.	min.	sec.		74	36	48	69	89
						(1)	(2)	(3)	(4)	(5)
C.	Began	No. 1, hr.	min.	sec.		836	347	593	746	683
	Finished	No. 5, hr.	min.	sec.		76	94	48	38	84
						(1)	(2)	(3)	(4)	(5)
D.	Began	No. 1, hr.	min.	sec.		586	893	938	783	547
	Finished	No. 5, hr.	min.	sec.		69	36	49	76	97
						(1)	(2)	(3)	(4)	(5)
E.	Began	No. 1, hr.	min.	sec.		379	895	647	396	495
	Finished	No. 5, hr.	min.	sec.		78	67	34	96	47

[2] The type and spacing here differ from the original.

begin to trace the mirrored star. Every time you get off the metal strip or lift the stylus from the metal you will hear a click and the counter will record one error. Keep on working until you hear the word "Stop." Then stop at once, but do not lift your stylus from the track until your record has been taken. Do not rest your hand on the board while you are tracing the star. Do not fail to cover every point of the star, making neat corners. If you get off the track come back on again immediately at the point where you left it. Your score will be the amount covered minus twice the number of errors. You are to work for accuracy rather than speed. At the word "Ready" catch hold of your sheets as you did in the addition test, and take your pencil in your right hand. Keep your eyes on your watch and at the word "Go" turn over your sheets and record in the proper spaces, the time at which you began. Then put your pencil on the table and begin to multiply the numbers of the first problem. The work is to be done mentally, nothing being written down until the entire result is obtained. The five figures of the result must be written down as fast as you can possibly write. Either keep your eyes closed or look at the example you are solving. Nothing is to be spoken out loud or whispered. You may work the examples in any way that is easiest for you, by the usual method of obtaining two partial products and adding them, by the method of multiplying by the first figure and adding in the obtained product as you multiply by the second figure, or by multiplying by both figures and adding in as you go along. This last method is the best and will enable you to do the largest number of problems when you know how to use it. Practice it according to this example:

$$\begin{array}{r} 378 \\ \underline{36} \end{array}$$

Multiply 8 by 6, which equals 48. Put down *8* mentally and carry 4. Multiply 7 by 6 which equals 42. Add 4 which equals 46. Multiply 8 by 3 which equals 24. Add 46 which equals 70. Put down *0* mentally and carry 7. Multiply 7 by 3 which equals 21. Add 7 which equals 28. Multiply 3 by 6 which equals 18. Add 28 which equals 46. Put down *6* mentally and carry 4. Multiply 3 by 3 which equals 9. Add 4 which equals *13*. The italicized figures which you in each case put down mentally are your answer: 13608.

Keep on working until you hear the word "Stop." Then record the time of ending, which should be twenty minutes later than you began. You are also to record the time of ending each set of five problems.

In all this work your aim should be to make the best possible score. The score is, of course, a composite of your speed and your accuracy, and will be kept as follows: The number of examples done in 20 minutes times 10, minus 2 for each wrong figure in the answer of each problem. That is, if all the figures in a five-place answer are wrong you get zero credit; if two are wrong, you get 6 credits, etc. You should therefore work carefully so as only very rarely to have errors in any answer.

IX. *Directions for Industrial Fatigue Test*

In this test I want you to pretend that you are a girl working at a machine in a factory. Your job will be to put these little cubes alternately on this inner square so that the edges just match. When I say "Ready" take one of the cubes in your right hand and when I say "Go" put this cube on the square. Then the arm will come along and sweep the cube off toward your left hand. You will catch it with your left hand, meanwhile putting the other block on the square with your right hand. If you should miss it, go right on as if nothing had happened. If the block falls down, pick it up and go right on. But remember every time you fail to put the block on, I shall count that 5 errors. The second thing to remember is not to let the rotating arm hit you,—and not to check its speed. Of course this machine will not hurt you, as a factory machine probably would. But if it does hit you I shall call out 3 errors. The third thing to remember is to get the cube exactly on the square. If you shove it over so that it touches one side of the outer square I shall call out 1 error. If it touches two sides of the outer square I shall call out 2 errors. I shall call out all the errors you make for my assistant to take down. At the end of five minutes I shall say "Stop." The machine goes fast, so keep your head and try not to make many of these errors.

X. *Directions for Reflex Wink Test*

Support your chin on the head rest and keep your eyes steadily fixed on some object on the level of your eyes at the end of the room. Look straight ahead of you. At odd moments when you are not expecting it, I will make the little hammer come up and hit the glass before your right eye. Of course this cannot hurt you, but at first you will wink at the sight and sound of the hammer. Now I want you to try not to wink when the hammer strikes. I will keep count of the number of times you are able to stop that wink.

Chronology of Humidity Experiment

Squad A, Oct. 4–16, 1915.
Squad B, Oct. 18–29, 1915.
Squad C, Nov. 1–12, 1915 (Subjects 1, 2, 3). Began under Wet Condition.
Squad D, Nov. 15–27, 1915 (Subjects 4, 5, 6, 7). Began under Dry Condition.
Squad E, Nov. 29–Dec. 10, 1915 (Subjects 8, 9, 10, 11). Began under Wet Condition.
Squad F, Dec. 13–24, 1915 (Subjects 12, 13, 14). Began under Dry Condition.
Squad G, Jan. 4–14, 1916 (Subjects 15, 16, 17, 18). Began under Wet Condition.
Squad H, Jan. 17–28, 1916 (Subjects 19, 20, 21, 22). Began under Dry Condition.

Physical Conditions in the Experimental Room[3]

Date	*Temperature* Dry Bulb	*Temperature* Wet Bulb	*Relative Humidity*	*Cu. Ft. Air per person per minute*	*CO_2 parts per 10,000. Average A.M. & P.M.*
	Squad C.	*Week Nov. 1–6th.*	*Condition 78°, 50 per cent.*		
Nov. 1	75.0	62.5	50	31.5	5.5
2	75.0	62.5	50	30.5	4.7
3	75.5	62.5	48	30.0	4.2
4	75.0	62.5	50	30.0	4.7
5	75.0	62.5	50	30.0	4.5
Average	*75.0*	*62.5*	*50*	*30.5*	*5.0*
	Squad C.	*Week Nov. 8–12th.*	*Condition 75°, 20 per cent.*		
Nov. 8	75.0	56.5	29	35.6	5.0
9	75.5	60.0	39	31.0	5.0
10	75.0	57.0	30	30.0	4.5
11	75.0	56.0	27	31.0	5.0
12	75.5	60.5	40	31.0	6.0
Average	*75.0*	*58.0*	*33*	*31.7*	*5.0*
	Squad D.	*Week Nov. 15–19th.*	*Condition 75°, 20 per cent.*		
Nov. 15	75.0	60.5	42	30.0	3.2
16	75.0	55.5	26	31.0	5.0
17	75.0	55.5	26	30.0	5.2
18	75.0	55.0	25	31.0	5.5
19	75.5	61.5	46	30.0 Re-circ.	12.0 x
Average	*75.0*	*57.5*	*33*	*30.0*	*6.0*
x—Stagnant after 2.25 P.M.					
	Squad D.	*Week Nov. 22–27th.*	*Condition 75°, 50 per cent.*		
Nov. 22	75.0	62.5	50	30.0	4.5
23	75.0	62.5	50	30.0	5.5
24	75.0	62.5	50	30.0	5.5
26	75.0	62.5	49	29.5	5.0
27	75.0	62.5	50	31.5	5.5
Average	*75.0*	*62.5*	*50*	*30.0*	*5.2*

[3] The maintenance of the physical conditions was in the hands of Mr. George T. Palmer and Mr. Philip Goldburg.

Date	Temperature Dry Bulb	Temperature Wet Bulb	Relative Humidity	Cu. Ft. Air per person per minute	CO_2 parts per 10,000. Average A.M. & P.M.
Squad E. Week Nov. 29–Dec. 3. Condition 75°, 50 per cent.					
Nov. 29	75.0	62.5	50	25.0 (Leakage)	5.5
30	75.0	62.5	50	27.0 "	5.5
Dec. 1	75.0	62.5	50	27.5 "	5.5
2	75.0	62.5	50	27.0 "	5.5
3	75.0	62.5	50	27.0 "	5.5
Average	*75.0*	*62.5*	*50*	*27.0*	*5.5*
Squad E. Week Dec. 6–10. Condition 75°, 20 per cent.					
Dec. 6	74.0	55.0	27	27.0 (Leakage)	4.5
7	75.5	54.5	21	27.5 "	5.0
8	75.0	55.0	24	29.0	5.5
8	75.0	54.0	21	29.0	4.5
10	75.0	53.5	19	29.0	—
Average	*75.0*	*54.5*	*22*	*28.0*	*5.0*
Squad F. Week Dec. 13–17. Condition 75°, 20 per cent.					
Dec. 13	75.5	55.0	23	29.0	5.0
14	75.0	53.5	20	30.0	5.5
15	75.0	53.5	20	30.0	5.0
16	75.0	53.5	20	30.0	5.0
17	75.0	54.0	21	30.0	4.5
Average	*75.0*	*54.0*	*21*	*30.0*	*5.0*
Squad F. Week Dec. 20–24. Condition 75°, 50 per cent.					
Dec. 20	75.5	63.5	52	29.5	5.5
21	75.0	62.5	49	29.5	4.7
22	75.0	62.5	50	28.5	5.0
23	75.0	62.5	50	29.5	5.0
24	75.0	62.5	49	30.0	4.5
Average	*75.0*	*62.5*	*50*	*29.5*	*5.0*
Squad G. Week Jan. 4–8. Condition 75°, 50 per cent.					
Jan. 4	75.0	62.5	49	30.5	4.3
5	75.0	62.5	50	28.2	4.5
6	75.0	62.5	50	27.0	4.7
7	75.0	62.5	50	27.0	4.5
8	75.0	62.5	50	27.0	4.5
Average	*75.0*	*62.5*	*50*	*28.0*	*4.5*
Squad G. Week Jan. 10–14. Condition 75°, 20 per cent.					
Jan. 10	75.0	55.0	24	27.0	5.3
11	75.5	54.5	22	27.5	5.3
12	75.0	53.5	20	27.5	5.0
13	75.0	55.0	25	28.0	5.0
14	75.0	55.5	19	27.5	4.5
Average	*75.0*	*54.5*	*22*	*27.5*	*5.0*

Date	*Temperature* Dry Bulb	*Temperature* Wet Bulb	*Relative Humidity*	*Cu. Ft. Air per person per minute*	*CO_2 parts per 10,000. Average A.M. & P.M.*
	Squad H.	*Week Jan. 17–21.*	*Condition 75°, 20 per cent.*		
Jan. 17	75.0	53.5	19	27.5	5.0
18	75.5	54.0	20	27.0	5.0
19	75.0	53.5	19	27.0	5.0
20	75.0	53.5	20	26.5	5.0
21	75.0	54.5	23	28.0	5.3
Average	*75.0*	*53.5*	*20*	*27.0*	*5.0*
	Squad H.	*Week Jan. 24–28.*	*Condition 75°, 50 per cent.*		
Jan. 24	75.0	63.0	51	27.5	4.5
25	75.0	62.5	50	25.5	5.5
26	75.0	62.5	49	27.5	5.0
27	77.0	65.0	51	27.5	4.5
28	75.0	62.0	47	28.0	5.7
Average	*75.5*	*63.0*	*50*	*27.0*	*5.0*

VITA

The writer, Lorle Ida Stecher, was born January 1, 1891, in St. Louis, Mo. She received her early education in the public schools of St. Louis, Indianapolis, Ind., and Philadelphia, Pa. She received the degree of Bachelor of Arts from Bryn Mawr College in 1912, and continued her studies as Graduate Scholar in the Department of Psychology during the years 1912–1914, under Professors C. E. Ferree, James H. Leuba, Matilde Castro and Kate Gordon, receiving the degree of Master of Arts in 1913. During the year 1914–1915 the writer was in residence at Columbia University, where she studied under Professors J. McKeen Cattell, Robert S. Woodworth, Edward L. Thorndike, John Dewey and Henry Suzzallo.