THE EFFECTS OF TWO SUPERIOR SYSTEMS OF CONTROLLED ILLUMINATION ON VISUAL ACUITY AND EYE FATIGUE

by

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INTRODUCTION

During the past few years, rapid strides have been made along the lines of artificial illumination. Lamp manufacturers have been making great progress in increasing the efficiency of lamps but, only in very few instances have the people installing these lamps for use, thought much of a "good" lighting installation when selecting a fixture for a particular purpose.

Eye trouble in this country is seriously on the increase, and is blamed to faulty electric lighting. Studies show that more people complain of head aches and other illness after working several hours under one type of lighting than when working the same length of time under other types.[1] Manufacturers have noticed a difference in amount of production under different lighting systems. These differences have served as incentives to study further under laboratory conditions the effect of various types of illumination upon the eye.

In an experiment of this kind, there are various limitations which must be dealt with fairly. Limitation in

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1 Ferre, C. E. and Rand, G. Relation of Illumination to Efficiency on Fine Work. Monthly Labor Review, Volume 24, p.509, 1927.

technique is probably the hardest to overcome. Difficulty in securing subjects who can devote sufficient time to the tests, variation in factors only a few of which can definitely be controlled, lack of uniformity in subjects as tested from day to day, distracting influences such as watching the clock, novelty of the environment, etc., are also among the limitations which might be mentioned.

EQUIPMENT

The equipment for this experiment consisted of a room with controlled ventilation, three indirect Luminaires, three Cooper Hewitt mercury arc lamps and testing apparatus, all of which will be described more in detail in the remainder of this section and in sections which follow.

The room was ventilated by an air conditioning plant, manufactured and distributed by the Carrier Company, Pittsburg, Pennsylvania. A diagram of the room and the essential features of the conditioner appears in Plate I.

Clean, fresh air is admitted by a pipe projecting through the roof of the building. On the diagram this is represented by the circle labeled "air pipe to roof". This air is washed by means of a water spray represented by the heavy blue lines. Most of the impurities having been washed

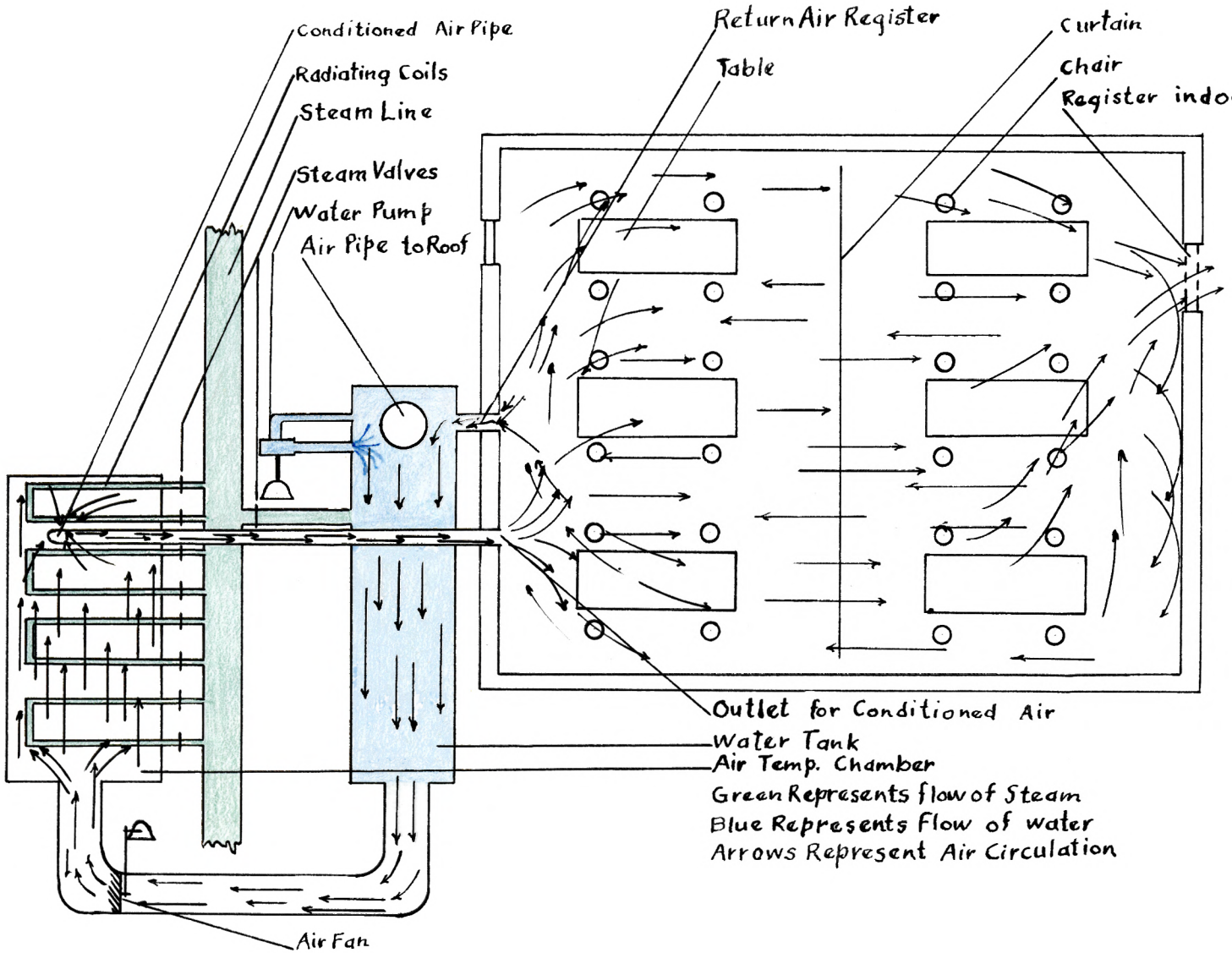
Conditioned Air Pipe
Radiating Coils
Steam Line
Steam Valves
Water Pump
Air Pipe to Roof
Return Air Register
Table
Curtain
Chair
Register indoor
Outlet for Conditioned Air
Water Tank
Air Temp. Chamber
Green Represents flow of Steam
Blue Represents Flow of water
Arrows Represent Air Circulation
Air Fan

Plate I

out, the air is drawn by the "air fan" into a closed box-like receptacle where it is allowed to pass over radiating coils. The air circulating around these coils takes up the proper amount of heat from them, and is blown out into the room through the "outlet pipe for conditioned air". The air represented by the arrows circulates to all parts of the room. Part of it goes out of the vent in the door on the far side of the room and the remaining air is reflected back to the "return air register".

The entire plant is thermostatically controlled so that when the desired conditions are once found no more adjustment is needed so long as the temperature outside does not exceed sixty degrees Fahrenheit. The water is sprayed out into the enclosed water tank by means of a centrifugal pump driven by a motor, indicated on Plate I as "air fan". Humidity is regulated thermostatically by allowing steam to pass from the "steam line" into the water. This heats the water to a temperature corresponding to the humidity desired in the room. By varying this temperature, it is possible to get conditions ranging from dry atmosphere to air fairly saturated with mositure or about seventy per cent relative humidity.

This conditioning plant provides ideal ventilation for thirty persons at one time, keeping the desired temperature

and humidity constant. All subjects were questioned[2] to determine the distracting influences of the operating machinery. The results showed that ninty-two per cent of all subjects were not annoyed by the mechanical noises. Only eight per cent indicated that the distractions retarded their study.

The automatic valves and all the air pressure controls are not shown on the diagram as they are of no consequence in this study. What has been explained is briefly the ventilation system of the room.

According to Marks[3] the correct effective temperature is sixty-five degrees Fahrenheit. This is the "comfort temperature" and is satisfactory to most people. It takes into account the effect of temperature and humidity on bodily needs. It is also stated by Marks that a humidity of about forty per cent is the most desirable and pleasant. Thus, with these two constants the room was kept at a temperature of seventy degrees Fahrenheit dry bulb thermometer reading, and fifty-five degrees Fahrenheit wet bulb. This combination gives a normal or comfort temperature of

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2 Questionnaire filled out by subject. Sample copy on page 44 of Appendix.

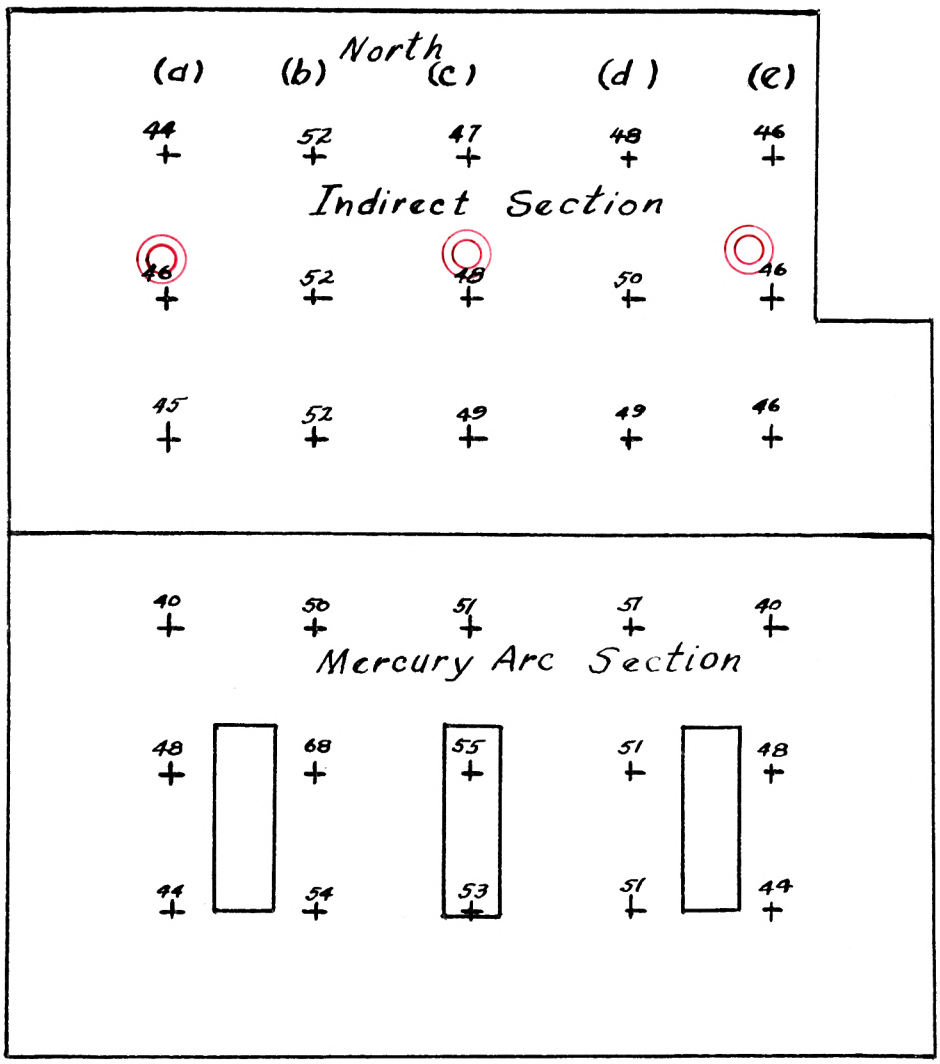
3 Author of Mechanical Engineers Handbook, p.1623.

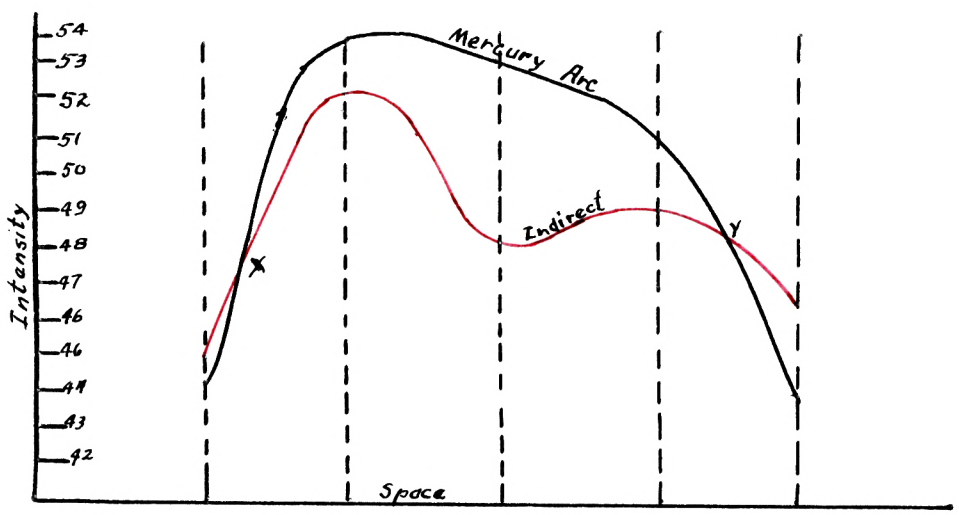
sixty-five degrees Fahrenheit and a relative humidity of forty per cent. These values for wet and dry bulb thermometer readings were taken from charts also presented in the handbook by Marks to which reference has already been made.

The lighting equipment is of two types--mercury arc and totally indirect. The mercury arc lights are manufactured and distributed by the Cooper Hewitt Company, a subsidiary of the General Electric Company. They operate on 110 volts A.C. and draw about four and five-tenths amperes, thus, using approximately four kilowatts of power. The indirect lights are type B put out by the Pittsburg Luminaire Company, Pittsburg, Pennsylvania. These are each equipped with 500 watt bulbs so that a comparison of powers consumed by each light may be drawn.

A diagram of the placement of these lights is shown in Plate II. The center line represents a heavy curtain which separates the room into two sections, thus, making it possible to use both lighting systems simultaneously. The curtain permitted ventilation but virtually made two rooms as far as the light was concerned. These lights were so placed that the variation of the intensities from one point in the room to another did not exceed eight foot candles. For example, if there were fifty foot candles on one side

Plate II


North
(a)
(b)
(c)
(d)
(e)
44
52
47
48
46
Indirect Section
46
52
48
50
46
45
52
49
49
46
Mercury Arc Section
40
50
51
51
40
48
68
55
51
48
44
54
53
51
44


Intensity
54
53
52
51
50
49
48
47
46
46
41
43
42
Mercury Arc
Indirect
X
Y
Space

of the room it would be desirable to have fifty foot candles on the other side. Also, if there were fifty foot candles at one point on one side it would be necessary to have fifty foot candles at every other point on that side. Thus, a person studying at one table should get the same light on his work as some one at the next table on the same side, or the same intensity as some one else on the other side of the curtain.

By repeated trials with a standard photometer the best balance and distribution of lighting effect was obtained when the indirect lights were arranged six feet apart and the mercury vapor lights were placed four and one-half feet apart. This gave illumination intensities measured in foot candles as represented by Plate II.

Measurement of intensity of both mercury arc and indirect lights was made at the intersection of horizontal and vertical lines laid off at three foot intervals. As previously stated, the straight horizontal line in Plate II represents the curtain which divides the room. Measurement was begun at a point three feet from the north wall and calculations were made at three foot intervals parallel to the curtain. The illumination was found to vary from forty-four foot candles to a maximum of fifty-two, and then

decreased to forty-six foot candles. The next line varied from forty-six to a maximum of fifty-two and decreased back to forty-six[4].

Suppose on each side of the curtain the average of these vertical points were taken. This would be averaging column (a), (b), (c), (d), and (e). These averages would give the mean illumination along that line. The curves at the bottom of the figure show these mean illuminations represented on the absissae and the space element on the ordinates. The black curve shows the distribution of the mercury arc light while the red curve shows the distribution of the indirect lights. The black curve rises more abruptly than the red. This shows that the distribution is not as good for the mercury vapor as it is for the indirect light. It also extends above the red curve which shows that the intensity is slightly greater for the mercury arc than for the indirect light. The intersections of the two curves X and Y show the points where the illumination is exactly the same. In other words, if points X and Y were

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4 These figures were obtained by averaging those readings which were taken before this problem was begun and the readings taken after the experiment was completed. The lights on each side had decreased in efficiency so the averages of these tests were taken as values for illumination which are represented on Plate II.

projected up into the room, somewhere along the line the intensity would be the same on each side of the curtain. It is at these points where the tests for visual acuity were taken. This will be more fully discussed in the next section.

The curves are not exactly symmetrical. On the indirect side this can perhaps be accounted for by the small projection in the side of the room. (See Plate II) Also, perhaps, different objects in the room reflected more light to one part than to another. Still another possibility and perhaps the most logical of all that the Mazda bulbs were not emitting exactly the same light intensity. This perhaps accounts for the slight unevenness of illumination on the indirect side.

On the mercury vapor side the differences in the evacuated tubes constitute the chief reason why the curve is not symmetrical. Three lights were used, two of which had new tubes. These two tubes radiated more light than the older one, thus, causing the left side of the curve to be steeper than the right. As these tubes are used, they gradually get weaker and eventually cease to operate.

The fact that these curves do not coincide with each other, and are not symmetrical makes no difference in one's visual acuity in this group of tests. Studies conducted by

Luckiesch show that with an increase from fifteen to twenty foot candles, the visual acuity test increases from 118 to 121 points. With an increase from twenty to thirty foot candles, there is an increase of 121 to 122 points in visual acuity. From thirty to forty foot candles there is no increase from 122 visual acuity test points. Thus, it can be said after thirty foot candles is reached, an added amount neither increases or diminishes visual acuity as long as it stays within certain limits and is the proper kind of light.[5]

In this experiment it was found that the intensity of illumination at any chair at any table differed from that at any other chair at any table not more than five foot candles. This is a comparatively small intensity when an illumination of forty or fifty foot candles is used. This variation of five foot candles either way will have very little affect on the speed of reading, visual acuity, or accuracy of vision.[6]

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5 The New Science of Seeing, M. Luckiesh. Transactions of the American Illuminating Society, Volume XXV, p.34, January 1930.

6 Ibid.

PROCEDURE

In an experiment of this kind, probably the greatest difficulty is in the developing of a proper technique. Tests developed by previous experimenters could not be used in an original problem of this kind. Trial and error seemed to be about the only way in which to proceed in a new field of this sort so numerous tests and methods were tried before a satisfactory one was reached.

Since this experiment was to deal with eye fatigue or loss of visual performance, the first thing to do was to find a means of measuring visual acuity with a sufficient degree of accuracy. This was a very difficult problem. First, because of the small amount of fatigue that takes place under these two very superior lights in the brief period of time that the subject studied under them. Second, in any test there is bound to be some learning. Third, a fairly long test had to be given "because even when the eye is greatly fatigued it has the power to attain a high degree of acuity for just a moment."[7]

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[7]Poffenberger, Applied Psychology. Its Principles and Methods, Second Edition, pp. 265-268.

Fourth, the method adopted would have to be understood easily by the subject and of such a nature as to be given conveniently by the examiner.

The General Electric Company[8] manufactures a set of cards (fifty-two in all) which may be used for testing visual acuity. The general character of these cards is shown in Plate III. They consist of small dots so spaced on the diagonal lines as to form certain letters of the alphabet. The one occupying the upper left space (Plate III) is O, the others in order are T, U, and Y. The complete alphabet was not used for the reason that some of the letters are difficult to distinguish.

Preliminary experimentation showed that familiarity with the test cards was a very important factor. The subject was given the cards and told to study them until he could see them instantly. He was then tested and retested until the improvement ceased.

The subjects were next given the pre test and final test under greatly reduced illumination in the hope that slight differences in acuity might be detected. This method

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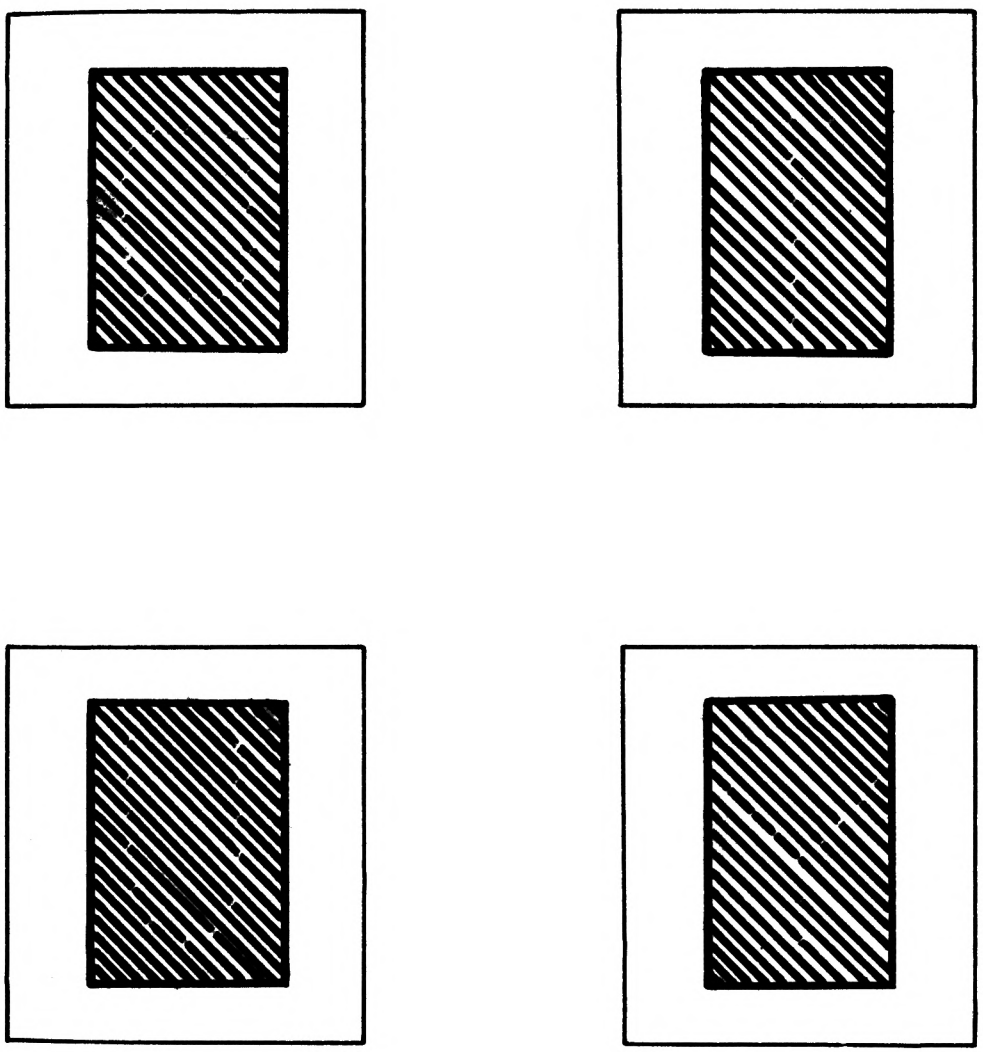
8 General Electric Manufacturing Company, Schenectudy, New York.

Plate III

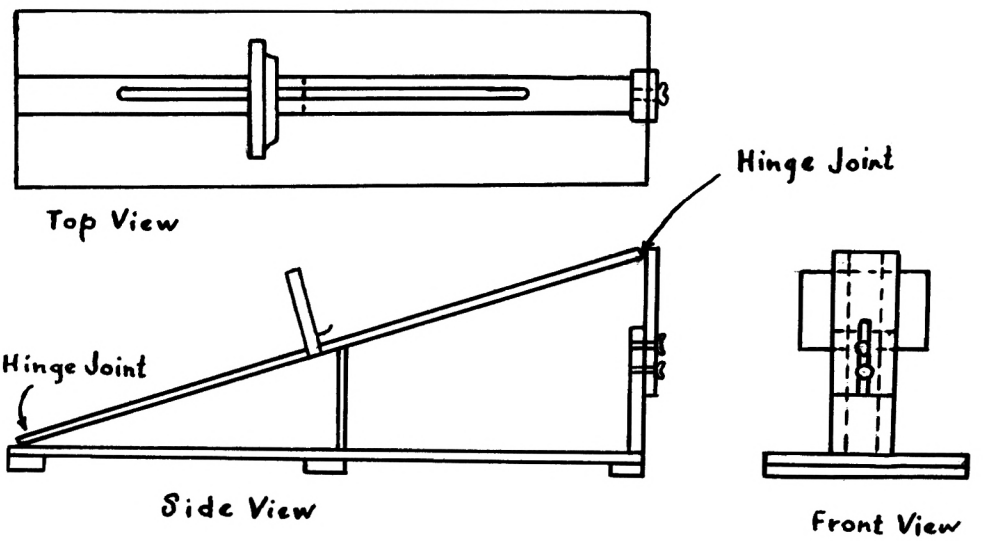


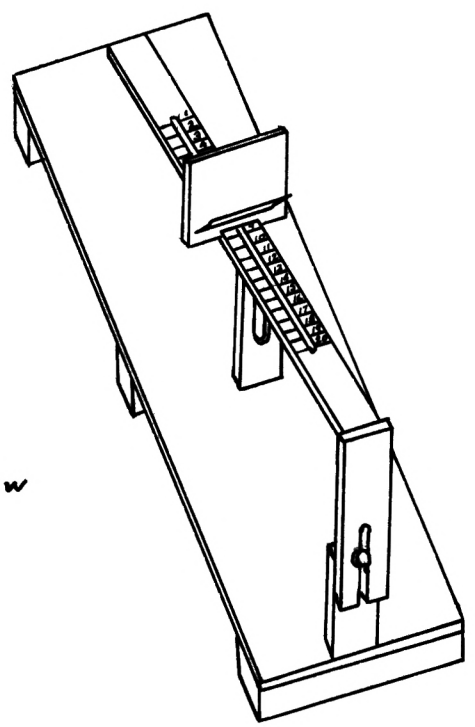
disclosed small differences in visual acuity, but was abandoned because of its inconvenience and the aversion of some subjects to the test under reduced illumination. These difficulties made it imperative that a better scheme of testing be devised.

The problem was finally solved by the simple device shown in Plate IV. Four views are given--the isometric, side, front, and top. It consists of an adjustable upright piece fastened to a base. A long adjustable bar is hinged to the top of the upright piece and to the far end of the base. A small rack, or card holder is fixed so that it may be moved backward or forward on a graduated scale which forms the adjustable bar. The subject rests his nose on the top of the upright piece and the examiner moves the card rack and cards until the subject can scarcely see them. The subject was asked to read and reread the cards until improvement ceased as was described previously. Then the test is ready to be administered.

After the first test, five cards were read by the subject and removed so that the examiner might be sure that the subject's eyes are correctly focused on the test cards. These cards were placed back in the deck and the subject told to begin. He read the cards aloud, each one being removed immediately by the examiner. The next card was then

Plate IV


Top View
Hinge Joint
Hinge Joint
Side View
Front View


Isometric View

read and removed until all the cards had been read. During this procedure the examiner was careful to catch the errors and the time taken to complete the set of cards. The time (stop watch reading), errors, and card rack setting were recorded and the subject proceded to his study. (The card rack setting is the distance from the subject's nose to the cards as read on the graduated scale of the adjustable bar).

At the close of the study period the student took the test position and the card rack was moved to the setting where the test was originally given. The same procedure was gone through as before with the time and errors observed and recorded.

To secure the greatest possible uniformity of test procedure all tests were made by the writer.

DATA AND RESULTS

At the end of each study period a questionnaire was filled out by the subject as has previously been stated. An examination of Table I showed that the test performance of the two sexes was not quite equal. In other words, the men and women did not react exactly alike due, probably, to some emotional differences. Though more of the women complained about bodily discomfort, men seemed to be disturbed more by slight noises and the like. Also the women seemed

to adjust themselves more readily to the mercury arc light, even though at first every subject complained of slight annoyance at the unusual quality of this light. Due to this emotional difference between men and women, separate studies were made of them.

The results of the 344 questionnaires are as follows: 98.5% said that the air in the laboratory seemed as pure as that outside; 92% said the air was never unpleasantly warm or unpleasantly cool; 92% said they were not annoyed by noises of the machinery; 98% said they believed that the results of this study period were as profitable as at their usual place of study; 70% said they accomplished more, 28% said there was no difference, and only 3% said they accomplished less work than they usually did during that length of study period; 75% said they were better able to adjust themselves under the indirect light than under the mercury arc light.

These results showed that the conditions for study from the student's viewpoint were practically ideal. It is worthy to note that 75% of the subjects favor the indirect light even though the results which follow show that the mercury vapor light is better.

Mention has already been made of the separation of men and women into separate groups due to emotional differences.

Subjects were also classified as to their visual defects.

Each subject was tested by Dr. Seiver of the Kansas State College Health Department for astigmatism, and for far and near-sightedness. Thus the classification includes (a) the entire group and (b) the following subgroups: men, women, normal eyed, astigmatics, far sighted, and near sighted. They will be studied in the above order.

Table I shows the forty-three subjects and all the average data taken on them during their eight study periods. As an example, subject one sits under the mercury arc light four different days for a period of two hours each. Each day initial tests are made on the time which is required to read the letters on the cards, also the number of errors made. At the end of the two-hour study period the test is again taken. The same procedure is followed for the indirect light. The results are tabulated as means of the four initial and final tests under each light.

A comparison of the means of the mean individual tests will undoubtedly show which is the superior of the two lights, and on this basis conclusions have been drawn. The probable errors of these means were found in order to show whether or not the data taken were statistically valid. In other words, whether the variations were due to actual differences or to chance.

Table I. Average Time and Errors of Forty-three Men and Women in Visual Acuity Tests Before and After Two Hours of Study Under Equated Intensities of Mercury Arc and Indirect Lights

	Mercury Arc Light				Indirect Light			
	Before Study		After Study		Before Study		After Study	
Subject Number	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
1	52.75	3.25	44.0	4.0	69.75	3.75	79.5	4.75
2	43.25	3.75	44.5	2.75	40.25	4.0	54.25	5.0
3	50.25	4.25	63.0	6.0	55.25	4.66	60.66	7.33
4	56.5	3.75	66.0	7.0	53.75	6.0	63.0	8.75
5	55.75	4.25	55.5	1.0	63.75	5.25	60.75	8.25
6	40.0	3.25	44.25	3.5	61.0	3.25	65.0	4.25
7	42.75	3.5	41.0	3.25	47.25	5.75	52.0	7.75
8	52.0	4.0	48.33	3.66	53.3	4.0	59.66	4.66
9	56.75	3.25	67.0	3.75	68.5	4.0	67.5	4.5
10	47.25	3.75	50.25	5.0	49.0	3.0	51.75	5.75
11	51.0	5.75	51.75	7.0	56.5	6.5	60.25	8.0

Table I. Continued.

12	65.25	1.75	66.25	2.5	74.75	3.5	92.5	6.5
13	39.75	2.5	41.75	3.0	42.5	3.5	58.25	4.5
14	72.0	1.5	69.25	2.75	68.5	3.0	84.0	4.75
15	44.33	3.33	46.0	3.33	44.66	4.0	52.33	4.33
16	46.66	2.66	45.0	3.0	39.0	5.33	47.33	7.0
17	39.5	2.75	43.75	3.0	43.75	4.5	44.5	4.0
18	49.0	2.75	45.25	3.5	54.75	3.5	61.25	4.0
19	43.5	2.25	43.25	1.75	48.0	3.5	52.0	4.0
20	48.5	2.75	55.75	5.5	48.75	2.25	53.5	4.75
21	40.25	3.5	44.5	3.25	46.5	3.75	50.5	3.25
22	40.0	2.0	41.0	2.5	40.0	2.0	41.0	6.0
23	39.25	4.0	42.75	5.25	47.75	4.25	46.75	4.25
24	66.75	4.0	69.75	3.75	77.25	5.5	102.5	7.5
25	53.75	2.0	44.0	3.5	61.75	4.25	73.0	7.5
26	42.25	3.25	41.5	2.5	50.75	6.5	53.75	7.0
27	64.33	3.0	58.0	2.0	78.0	4.33	85.0	5.33

Table I. Continued.

28	56.75	5.75	48.5	5.25	53.25	6.5	61.25	9.75
29	48.25	4.25	37.75	3.75	49.75	4.0	49.75	4.75
30	35.0	2.25	33.25	2.75	45.5	5.0	41.0	5.25
31	60.75	3.75	63.0	4.0	55.75	2.75	59.0	5.0
32	38.66	1.33	43.0	2.33	46.0	3.33	51.0	3.0
33	44.0	2.5	44.5	3.75	51.5	3.5	47.0	5.75
34	39.15	3.5	39.25	4.25	42.5	2.75	40.0	3.25
35	42.25	.5	41.5	.75	46.5	1.75	46.75	3.5
36	33.25	1.0	39.5	.5	53.0	4.5	48.75	4.5
37	50.5	3.5	42.75	3.75	52.75	3.75	45.0	3.5
38	48.75	4.75	49.25	4.75	52.75	7.0	53.0	6.25
39	38.25	3.25	37.75	3.25	57.5	7.0	50.25	5.75
40	64.25	3.5	56.0	3.25	69.0	5.0	75.75	5.75
41	41.75	3.25	44.0	3.0	47.0	3.0	45.75	4.0

Table I. Continued.

42	39.66	4.33	40.33	2.33	53.33	4.66	58.33	5.33
43	38.0	4.25	41.0	6.0	49.0	7.0	47.0	8.0
Mean	47.05	3.22	48.23	3.53	53.72	4.31	57.95	5.58
Probable Error	1.36	.11	.96	.15	1.12	.14	1.48	.17

Measure of Fatigue

Mercury Arc Time$_2$ - Mercury Arc Time$_1$
48.22 - 47.05 1.17 sec. P.E. is 1.66 sec.
Indirect Time$_2$ - Indirect Time$_1$
57.95 - 53.72 4.23 sec. P.E. is 1.86 sec.
Difference is 3.06 sec. P.E. of difference is 2.49 sec.

Mercury Arc Errors$_2$ - Mercury Arc Errors$_1$
3.53 - 3.22 .31 errors P.E. is .18 errors
Indirect Errors$_2$ - Indirect Errors$_1$
5.58 - 4.31 1.27 errors P.E. is .22 errors
Difference is .96 errors P.E. of difference is .29 errors

Measure of Visual Acuity

Indirect Time$_1$ - Mercury Arc Time$_1$
53.72 - 47.06 6.66 sec. P.E. is 1.76 sec.
Indirect Time$_2$ - Mercury Arc Time$_2$
57.95 - 48.23 9.72 sec. P.E. is 1.77 sec.

Indirect Errors$_1$ - Mercury Arc Errors$_1$
4.31 - 3.22 1.09 errors P.E. is 1.78 errors
Indirect Errors$_2$ - Mercury Arc Errors$_2$
5.58 - 3.53 2.05 errors P.E. is .22 errors

One would judge that the subject would be somewhat fatigued after the two-hour study period. If the lights were of equal value so far as ease to the eye is concerned, the same loss of visual acuity might be expected under one light as under the other. Thus, in measuring this decrease in vision, the difference in test time before study and the test time after study should be some indication of the amount of fatigue.

It appears logical that the subject would make more errors on the test at the end of the study period than at the beginning. Errors, therefore, can also be used as a measure of the declining eye efficiency. With these two measures, we can make direct comparisons of eye fatigue for the two different kinds of light.

In Table I, there is a difference of 1.17 seconds between the second mercury arc test time (designated by mercury arc time$_2$ in tables) and the first mercury arc test time (designated by mercury arc time$_1$ in tables) with a probable error of 1.66. Since the probable error of this difference is larger than the difference, it can be said that there is no valid difference between the first and second test times, and thus there is probably little or no loss of visual acuity as measured by time.

When the same procedure was worked out for the indirect

light, it was found that there was a difference of 4.23 seconds with a probable error of 1.86. This shows that the difference in time required is 2.3 times its own probable error. This difference is more reliable but hardly valid statistically. Also, it can be seen that fatigue as measured by time is 3.6 times greater under the indirect light than it is under the mercury vapor light. Accordingly, there is much more fatigue, using time as a measure, under the indirect light than there is under the mercury vapor light.

Using errors as a means of comparison, it was found that on the mercury vapor side there was an average of .3 more errors made on the second test than were made on the first test. The probable error of the difference is .18. Since this figure is less than twice its probable error, a great amount of reliability cannot be assigned to the difference even though the trend shows fatigue. With the indirect lights, the difference in errors is 1.27 with a probable error of .22. This result is statistically valid as the number is approximately 6.3 times its probable error[9]. The fatigue measured by errors is about 4.1 times as great

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[9] Hollsinger's Statistical Methods in Education.

under the indirect light as under the mercury arc light.

Some very interesting results were noted in regard to visual acuity. It was found that it took 6.67 seconds longer to take the beginning test under the indirect light than it took under the mercury arc light with a probable error of 1.76. This is statistically valid. It was also found that it took 9.73 seconds longer for the second test under the indirect light than under the mercury arc light.

The errors showed the same results. The subjects made 1.09 more errors with a probable error of .18 under the indirect light than under the mercury arc for the beginning test. The difference is six times its probable error and is, therefore, statistically valid. In the final test, the subjects made 2.05 more errors with a probable error of .22 under the indirect light than under the mercury arc light. This is also statistically valid as the difference is nine times its probable error. These data are very conclusive evidence that the visual acuity is better under the mercury vapor lights than it is under the indirect light using either time or errors for measures of acuity.

Another possible way of working out relationships would be to use per cents. It was found by examination of Table I that 58.13 per cent of the subjects under the mercury arc light equaled or exceeded their initial test time in the

final test. The probable error of this percentage is 5.08. Under the indirect light 74.41 per cent, with a probable error of 4.51, of the subjects equaled or exceeded their initial test time in the final test. It was found that 16.28 per cent, with a probable error of 6.8, more people equaled or exceeded their initial test time in the final test under the indirect light than under the mercury arc light. The difference is 2.4 times its probable error.

The errors were treated in exactly the same manner and it was found that 18.61 per cent more people equaled or exceeded the initial number of errors in the final test. The probable error of this percentage is 5.08. The difference is three times its probable error.

The tables which follow and their contents are given the same treatment as that used in Table I. The same symbols and form of tabulation are repeated.

Table II shows means and probable errors of average time and errors of twenty-three men[10] in visual acuity tests before and after two hours of study under equated intensities of mercury arc and indirect lights. The results show a marked loss of visual acuity using errors as a measure of

[10] Men subjects were 2,3,4,6,7,8,9,12,13,14,15,16,22,24,26, 27,31,32,34,37,38,40, and 42.

fatigue. This group of subjects made 1.09 more errors, with a probable error of .356, under the indirect light in the second test than they did the corresponding test under the mercury vapor light. When the time was used as a measure of visual efficiency, the results were not so conclusive. The difference and its probable error are approximately equal so no definite statement can be made. However, there is a definite trend that tends to show the mercury arc light superior.

Table II. Mean performance of men under the mercury arc and indirect lights.

	Mercury Arc Light			
	Before		After	
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	48.93	3.23	51.53	3.47
Probable Error	2.34	.13	1.51	.16
	Indirect Light			
Mean	55.08	4.29	61.77	5.62
Probable Error	2.36	.17	2.34	.23

Measure of Fatigue

$Mercury\ Arc\ Time_2 - Mercury\ Arc\ Time_1$
$51.53 - 48.93 = 2.60$ sec. P.E. is 2.79 sec.
$Indirect\ Time_2 - Indirect\ Time_1$
$61.77 - 55.08 = \underline{6.69}$ sec. P.E. is $\underline{3.32}$ sec.
Difference is $\overline{4.09}$ sec. P.E. of difference is $\overline{4.34}$ sec.

Mercury Arc Errors$_2$ - Mercury Arc Errors$_1$
3.47 - 3.23 = .24 errors P.E. is .21 errors
Indirect Errors$_2$ - Indirect Errors$_1$
5.62 - 4.29 = 1.33 errors P.E. is .29
Difference is 1.09 errors P.E. of difference is .36 errors

Measure of Acuity

Indirect Time$_1$ - Mercury Arc Time$_1$
55.08 - 48.93 = 6.15 sec. P.E. is 3.32 sec.
Indirect Time$_2$ - Mercury Arc Time$_2$
61.77 - 51.53 = 10.24 sec. P.E. is 2.79 sec.

Indirect Errors$_1$ - Mercury Arc Errors$_1$
4.29 - 3.23 = 1.06 errors P.E. is .22 errors
Indirect Errors$_2$ - Mercury Arc Errors$_2$
5.62 - 3.47 = 2.15 errors P.E. is .28 errors

Using per cent as a means of comparison, it was found that under the mercury arc light 65 per cent of the men subjects equaled or exceeded their initial test time in the final test. The probable error is 6.7. Under the indirect light, 87 per cent with a probable error of 4.73 equaled or exceeded their initial test time in the final test. It can be said then that 22 per cent more people equaled or exceeded their initial test time in the final test under the indirect light than under the mercury arc light. The probable error of this difference is 8.21 per cent.

Using errors for comparison, it was found that 17.6 per cent, with a probable error of 8.54 per cent, more people equaled or exceeded the initial number of errors in the final test under the indirect light than under the mercury arc light. Both time and errors as measures of fatigue

indicate that the mercury arc light is superior to the indirect light with the men.

Table III shows means and probable errors of average time and errors of twenty women[11] in visual acuity tests before and after two hours of study under equated intensities of mercury arc and indirect lights. In addition to these tabulated results, it was found that 50 per cent, with a probable error of 7.55, of the women subjects equaled or exceeded the initial test time in the final test under the mercury arc light. When these same subjects studied under the indirect light, it was found that 60 per cent, with a probable error of 6.88, equaled or exceeded the initial test time in the final test. In other words, 10 per cent, with a probable error of 10.21, more people equaled or exceeded the initial test time in the first test under the indirect light than under the mercury arc light.

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[11] Women subjects were 1,5,10,11,17,18,19,20,21,23,25,28,29, 30,33,35,36,39,41, and 43.

Table III. Mean performance of women under the mercury arc and indirect lights.

Mercury Arc Light

	Before		After	
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	44.9	3.2	44.42	3.59
Probable Error	1.01	.19	.87	.26

Indirect Light

Mean	52.16	4.34	53.56	5.48
Probable Error	.95	.22	1.40	.26

Measure of Fatigue

$Time_2$ - $Time_1$
44.42 - 44.9 = -.48 sec. P.E. is 1.33 sec.
$Time_2$ - $Time_1$
53.56 - 52.16 = 1.40 sec. P.E. is 1.69 sec.
Difference is 1.88 sec. P.E. of difference is 2.15 sec.

$Errors_2$ - $Errors_1$
3.59 - 3.2 = .39 errors P.E. is .32 errors
$Errors_2$ - $Errors_1$
5.48 - 4.34 = 1.14 errors P.E. is .34 errors
Difference is .75 errors P.E. of difference is .46 errors

Measure of Acuity

$Time_1$ - $Time_1$
52.16 - 44.90 = 7.26 sec. P.E. is 1.39 sec.
$Time_2$ - $Time_2$
53.56 - 44.42 = 9.14 sec. P.E. is 1.64 sec.

$Errors_1$ - $Errors_1$
4.34 - 3.2 = 1.14 errors P.E. is .29 errors
$Errors_2$ - $Errors_2$
5.48 - 3.59 = 1.89 errors P.E. is .37 errors

This figure is not statistically valid. Using errors, a very similar story is told except that the figure is more reliable. Twenty per cent more people, with a probable error of 8.89 per cent, equaled or exceeded the initial number of errors in the second test under the indirect light than under the mercury arc light. The data for the women subjects are not so conclusive as that for the whole group, and for the men group, but that is due partly to larger numbers of subjects in the first two groups.

Table IV shows means and probable errors of average time and errors of fourteen normal eyed subjects[12] in visual acuity tests before and after two hours of study under equated intensities of the mercury arc and indirect lights. Due to the size of the probable errors, it cannot be said definitely that one light is more fatiguing, but the trend favors the mercury arc light. In comparing the visual acuity under the two lights, it can be said that the mercury arc light almost certainly affords better visual acuity than the indirect light. Both time and errors give valid results.

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[12] Normal eyed subjects were 3,4,8,9,17,18,21,24,26,30,32,34, 35, and 37.

Table IV. Mean performance of normal eyed subjects under the mercury arc and indirect lights.

	Mercury Arc Light			
	Before		After	
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	46.57	3.01	48.71	3.55
Probable Error	1.49	.17	1.95	.25
	Indirect Light			
Mean	51.97	4.17	56.35	4.93
Probable Error	1.64	.20	2.58	.31

Measure of Fatigue

$Mercury\ Arc\ Time_2 - Mercury\ Arc\ Time_1$
$48.71 - 46.57 = 2.14$ sec. P.E. is 2.45 sec.
$Indirect\ Time_2 - Indirect\ Time_1$
$56.35 - 51.97 = \underline{4.38}$ sec. P.E. is $\underline{3.05}$ sec.
Difference is $\overline{2.24}$ sec. P.E. of difference is $\overline{3.91}$ sec.

$Mercury\ Arc\ Errors_2 - Mercury\ Arc\ Errors_1$
$3.55 - 3.01 = .54$ errors P.E. is .30 errors
$Indirect\ Errors_2 - Indirect\ Errors_1$
$4.93 - 4.17 = \underline{.76}$ errors P.E. is $\underline{.38}$ errors
Difference is $\overline{.22}$ errors P.E. of difference is $\overline{.49}$ errors

Measure of Acuity

$Indirect\ Time_1 - Mercury\ Arc\ Time_1$
$51.97 - 46.57 = 5.40$ sec. P.E. is 2.21 sec.
$Indirect\ Time_2 - Mercury\ Arc\ Time_2$
$56.35 - 48.71 = 7.64$ sec. P.E. is 3.23 sec.

$Indirect\ Errors_1 - Mercury\ Arc\ Errors_1$
$4.17 - 3.01 = 1.16$ errors P.E. is .26 errors
$Indirect\ Errors_2 - Mercury\ Arc\ Errors_2$
$4.93 - 3.55 = 1.38$ errors P.E. is .40 errors

In addition to the data listed in the tables, the following percentage comparisons may be used: sixty per cent of the normal eyed subjects, with a probable error of 8.50, equaled or exceeded the initial test time in the second test under the mercury arc light. It was found that 73.33, with a probable error of 7.67 per cent, equaled or exceeded the initial test time in the final test under the indirect light. There is a difference of 13.33 per cent, with a probable error of 11.46 per cent, which means that 13.33 per cent more people equaled or exceeded the initial test time in the second test under the indirect light than under the mercury vapor light. This difference only slightly exceeds its own probable error.

Using errors as a measure, it was found that there was no difference between the two lights since 73 per cent equaled or exceeded the number of errors of the initial test in the final test under both the indirect light and the mercury arc light.

These results for the normal eyed group are not so conclusive, but they do show a trend. Perhaps, the greatest difficulty is that there are not enough subjects in this classification to give valid results.

Table V shows means and probable errors of average time and errors of twelve astigmatic subjects[13] in visual acuity tests before and after two hours of study under equated intensities of mercury arc and indirect lights. Results show a very decided advantage for the mercury arc light for both ease to the eye and ability to see objects well.

Besides the tabulated data given under Table V, the following per cents have been worked out: It was found that 58.33 per cent, with a probable error of 9.58 per cent, of the subjects equaled or exceeded the initial test time in the final test, under the mercury arc light. Also, 91.67 per cent, with a probable error of 5.32 per cent, equaled or exceeded the initial test time in the second test under the indirect light. There is, therefore, a difference of 33.34 per cent, with a probable error of 10.95 per cent, or there were 33.34 per cent more people who equaled or exceeded the initial test time in the final test under the indirect light than under the mercury arc light.

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13 Astigmatic subjects were 10,12,19,20,25,26,28,29,31,39, 40, and 42.

Table V. Mean performance of astigmatic subjects under the mercury arc and indirect lights.

	Mercury Arc Light			
	Before		After	
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	52.54	3.36	49.99	3.51
Probable Error	1.81	.21	1.77	.23
	Indirect Light			
Mean	58.24	4.23	63.51	5.79
Probable Error	2.00	.27	2.71	.33

Measure of Fatigue

$Mercury\ Arc\ Time_2 - Mercury\ Arc\ Time_1$
$49.99 - 52.54 = -2.55$ sec. P.E. is 2.53 sec.
$Indirect\ Time_2 - Indirect\ Time_1$
$63.51 - 58.24 = 5.27$ sec. P.E. is 3.37 sec.
Difference is 7.82 sec. P.E. of difference is 4.22 sec.

$Mercury\ Arc\ Errors_2 - Mercury\ Arc\ Errors_1$
$3.51 - 3.36 = .15$ errors P.E. is .31 errors
$Indirect\ Errors_2 - Indirect\ Errors_1$
$5.79 - 4.23 = 1.56$ errors P.E. is .42 errors
Difference is 1.41 errors P.E. of difference is .52 errors

Measure of Acuity

$Indirect\ Time_1 - Mercury\ Arc\ Time_1$
$58.24 - 52.54 = 5.70$ sec. P.E. is 2.69 sec.
$Indirect\ Time_2 - Mercury\ Arc\ Time_2$
$63.51 - 49.99 = 13.52$ sec. P.E. is 3.23 sec.

$Indirect\ Errors_1 - Mercury\ Arc\ Errors_1$
$4.23 - 3.36 = .87$ errors P.E. is .34 errors
$Indirect\ Errors_2 - Mercury\ Arc\ Errors_2$
$5.79 - 3.51 = 2.28$ errors P.E. is .40 errors

On the basis of errors, it was found that 50 per cent, with a probable error of 10.95 per cent, more people equaled or exceeded the number of errors of the initial test in the final test, under the indirect light than under the mercury arc light. The results of the various comparisons would indicate that the mercury vapor light is somewhat better for the astigmatic group.

Table VI shows means and probable errors of average time and errors of seven far-sighted subjects[14] in visual acuity tests before and after the two hours of study under equated intensities of mercury arc and indirect lights. Results are shown in tabular form for both measures of fatigue and visual acuity. Here again, the size of the group prevents a very good treatment of the data, but what data are presented seem to be very much in favor of the mercury arc light. Besides these tabulated data, a few percentages may well be given. It was found that 42.86 per cent, with a probable error of 12.74 per cent, more people equaled or exceeded the initial test time in the final test under the indirect light than under the mercury arc light. Also, 28.58 per cent, with a probable error of 11.53 per cent, more subjects equaled or exceeded the initial number of errors in the final test under the indirect light than under

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[14] Far-sighted subjects were 1,2,6,7,14,15, and 22.

the mercury arc light.

Table VI. Mean performance of far-sighted subjects under the mercury arc and indirect lights.

	Mercury Arc Light			
	Before		After	
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	47.87	2.94	47.14	3.15
Probable Error	2.85	.20	2.35	.13
	Indirect Light			
Mean	53.05	3.68	61.15	5.26
Probable Error	3.08	.27	4.34	.29

Measure of Fatigue

$Mercury\ Arc\ Time_2 - Mercury\ Arc\ Time_1$
$47.14 - 47.87 = -.73$ sec. P.E. is 3.69 sec.
$Indirect\ Time_2 - Indirect\ Time_1$
$61.15 - 53.05 = 8.10$ sec. P.E. is 5.32 sec.
Difference is 8.83 sec. P.E. of difference is 6.47 sec.

$Mercury\ Arc\ Errors_2 - Mercury\ Arc\ Errors_1$
$3.15 - 2.94 = .21$ errors P.E. is .24 errors
$Indirect\ errors_2 - Indirect\ Errors_1$
$5.26 - 3.68 = 1.58$ errors P.E. is .40 errors
Difference is 1.37 errors P.E. of difference is .46 errors

Measure of Acuity

$Indirect\ Time_1 - Mercury\ Arc\ Time_1$
$53.05 - 47.87 = 5.18$ sec. P.E. is 4.10 sec.
$Indirect\ Time_2 - Mercury\ Arc\ Time_2$
$61.15 - 47.14 = 14.01$ sec. P.E. is 4.93 sec.

$Indirect\ Errors_1 - Mercury\ Arc\ Errors_1$
$3.68 - 2.94 = .74$ errors P.E. is .34 errors
$Indirect\ Errors_2 - Mercury\ Arc\ Errors_2$
$5.26 - 3.15 = 2.11$ errors P.E. is .32 errors

Table VII shows the results obtained with eight near-sighted subjects[15]. Due to the small size of the group, it is very difficult to draw any definite conclusions.

The percentage relationships indicate that 87.5 per cent, with a probable error of 7.76 per cent, equaled or exceeded the initial test time in the final test under the mercury arc light. Only 25 per cent, with a probable error of 10.39 per cent, equaled or exceeded the initial test time in the final test under the indirect light. This result indicates that the indirect light is better. This inconsistency with previous data is probably due to the size of the group and the possible inaccuracy of measurement of them.

The error record, however, tells a different story. It was found that 25 per cent, with a probable error of 13.89 per cent, more persons equaled or exceeded the initial number of errors in the second test under the indirect light than under the mercury vapor light.

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15 Near-sighted subjects were 5,11,23,33,36,38,41, and 43.

Table VII. Mean performance of near-sighted subjects under the mercury arc and indirect lights.

	Before		After	
	Mercury Arc Light			
	$Time_1$ in Seconds	$Errors_1$	$Time_2$ in Seconds	$Errors_2$
Mean	43.97	3.72	46.03	3.90
Probable Error	1.68	.33	1.25	.52
	Indirect Light			
Mean	52.65	5.12	51.16	6.12
Probable Error	1.23	.35	1.37	.40

Measure of Fatigue

$Mercury\ Arc\ Time_2 - Mercury\ Arc\ Time_1$
$46.03 - 43.97 = 2.06$ sec. P.E. is 2.09 sec.
$Indirect\ Time_2 - Indirect\ Time_1$
$51.16 - 52.65 = 1.49$ sec. P.E. is 1.84 sec.
Difference is 3.55 sec. P.E. of difference is 2.56 sec.

$Mercury\ Arc\ Errors_2 - Mercury\ Arc\ Errors_1$
$3.90 - 3.72 = .18$ errors P.E. is .61 errors
$Indirect\ Errors_2 - Indirect\ Errors_1$
$6.12 - 5.12 = 1.00$ errors P.E. is .54 errors
Difference is .82 errors P.E. of difference is .81 errors

Measure of Acuity

$Indirect\ Time_1 - Mercury\ Arc\ Time_1$
$52.65 - 43.97 = 8.68$ sec. P.E. is 2.08 sec.
$Indirect\ Time_2 - Mercury\ Arc\ Time_2$
$51.16 - 46.03 = 5.13$ sec. P.E. is 1.85 sec.

$Indirect\ Errors_1 - Mercury\ Arc\ Errors_1$
$5.12 - 3.72 = 1.40$ errors P.E. is .48 errors
$Indirect\ Errors_2 - Mercury\ Arc\ Errors_2$
$6.12 - 3.90 = 2.22$ errors P.E. is 6.55 errors

CONCLUSIONS

All trends indicated that the mercury vapor light is superior for visual acuity and less fatiguing to the eye. Statistical treatment of test results, where the whole group was taken, showed a valid difference in the number of errors in favor of the mercury vapor light, and almost invariably a shorter time in reading the test cards. In the case of the larger subdivided groups (men, women, normal vision, and astigmatic) the same general results were found though the differences were not reliable. The two other groups were too small for definite conclusions, but the trends favored the mercury arc light.

APPENDIX

The list of subjects who made this experiment possible is as follows:

1. Billings
2. Bryan
3. Burch, C.
4. Burch, V.
5. Call
6. Coblentz
7. Cook
8. Darnell
9. De Puy
10. Droz
11. Easterday
12. Fleenor
13. Fry
14. Gemmell
15. Gilladett
16. Holliday
17. Hooper
18. Horton
19. Kirkpatrick
20. Marshall
21. McMullen
22. Miller
23. Oliphont
24. Pattison
25. Paulson
26. Peters
27. Peterson

28. Reed
29. Reid
30. Sands
31. Schall
32. Stukey
33. Stone
34. Thompson
35. Trusler
36. Vail
37. Walters
38. Wann
39. Williams
40. Witt
41. Wolbert
42. Woolcott
43. Zircle

Individual Data Sheet

Name_____ Age_____ Sex_____

Eye test_____

Do you wear glasses? Yes☐ , No☐ , Occasionally ☐

College Student ☐ Faculty ☐ High School Student ☐

	Mercury Vapor Lamp				Indirect Lamp			
Date								
Initial test time								
Number errors								
Final test time								
Number errors								
Time period								
Zone								
Outside temp.								

Remarks

_____

Questions to be Answered by the Subject

1. Did the air in the laboratory seem to be as pure as that outside? Yes ☐ No ☐

2. Was the laboratory ever unpleasantly warm or unpleasantly cool? Yes ☐ No ☐

3. Were you annoyed by the noises of machinery?

   Yes ☐ No ☐

4. Were there other distractions? If so, what?

   Yes ☐ No ☐

5. Do you believe the results of this study period were as profitable as your usual place of study?

   Yes ☐ No ☐

6. Did you accomplish more or less work than you usually do during the same length of study period?

   More ☐ Less ☐ No difference ☐

7. To which of the two lights were you able to adjust yourself more readily? (After first test).

   Mercury Vapor ☐ Indirect ☐

8. Do you know what the results of your tests have been?

   Yes ☐ No ☐

9. Were you as physically and mentally alert as usual during this test? Yes ☐ No ☐

Remarks, if any_____

Name_____

Date_____

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