1970

An Eye-movement Analysis of Five Ink Colors Printed on Yellow Stock

Robert Charles Clappsy

AN EYE-MOVEMENT ANALYSIS OF FIVE INK COLORS PRINTED ON YELLOW STOCK

BY

ROBERT CHARLES CLAPPSY

A thesis submitted
in partial fulfillment of the requirements for the
degree Master of Science, Major in
Printing Management, South Dakota
State University

1970

AN EYE-MOVEMENT ANALYSIS

OF FIVE INK COLORS PRINTED ON YELLOW STOCK

This thesis is approved as a creditable, independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Adviser Date

Head, Printing and Journalism Department Date

ACKNOWLEDGMENTS

The writer wishes to express his sincere appreciation to Assistant Professor Paul H. Jess for his guidance, recommendation, and constructive criticism in the writing and preparation of this study. A sincere thanks also to Dr. George H. Phillips for his encouragement and guidance throughout this study.

Finally, a "thank you" to my wife whose moral support was a sustaining and immeasurable factor during the course of this study.

RCC

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF TABLES (continued)

CHAPTER I

INTRODUCTION

Need for the Study

The use of color combinations of print and paper by commercial printers has increased steadily since 1930. The relation of color-of-print to color-of-background is an important factor to be considered in printing because color does affect legibility. The increased use of color emphasizes the need for scientific knowledge concerning the effect on legibility of various color combinations of print and background. Such scientific knowledge demands relevant research in many areas of color printing.

Statement of the Problem

This study will try to determine the effects on eye-movements of various ink colors printed on a controlled yellow stock. This information would be useful to printers when working with color combinations.

Review of the Literature

A considerable amount of research in color has been done by psychologists who were concerned with both the pedagogical and psychological aspects of reading. Tinker,[1] in his book Bases for Effective Reading, noted four experimental procedures used to investigate the legibility of colored print on a colored background. These were: perceptibility during short exposures; perceptibility at a distance; speed-of-reading; analysis of eye-movements.

Miyake, Dunlap, and Cureton,[2] using a short-exposure method, measured the legibility of black and colored numbers on colored and black backgrounds. By means of a flash perception with a 3-second interval, they found black on white (27.00), white on black (26.94), yellow on black (26.80), and green on black (26.27) to be among the most legible combinations. (Scores noted here are percentages of correctly reported numerals.) In contrast, red on black (03.53) and green on black (03.67) were noted to be far less legible.

Griffing and Franz[3] found that because of loss of contrast, all "gray" and tinted papers were inferior to

---

1 Miles A. Tinker, Bases for Effective Reading, Minneapolis: University of Minnesota Press, 1965, pp. 162-66.

2 Ruth Miyake, Jack W. Dunlap, and Edward Cureton, "The Comparative Legibility of Black and Colored Numbers on Colored and Black Backgrounds," Journal of General Psychology, 3: 340-43 (June 1930).

3 Harold Griffing and Shepherd I. Franz, "On the Conditions of Fatigue in Reading," Psychological Review, 3: 513-30 (September 1896).

white. The authors suggested that whiter papers be used when legibility was extremely important.

Tinker,[4] in a short-exposure experiment, investigated the effect of color on perceptibility of block capital letters on white backgrounds. The exposure time was three seconds. The average number of letters of each color reported correctly was used to rank the colors in terms of their effect on perceptibility. He found that black on white was more readily perceived than were the other colors tested. He attributed this to the difference of contrast (or luminosity) between print and paper being greatest in the black-on-white sample.

Perceptibility measured at a distance was the criterion used by Sumner[5] when he studied the relative legibility of 42 color combinations of print and background. The three most legible combinations were blue on grey, black on grey, and black on yellow. The three worst combinations were black on blue, yellow on white, and blue on black. The author suggested that legibility depended upon luminosity differences between the symbol and

---

4 Miles A. Tinker, "The Effect of Color on Visual Apprehension and Perception," Genetic Psychological Monographs, 11: 61-136 (February 1932).

5 F. C. Sumner, "Influence of Color on Legibility of Copy," Journal of Applied Psychology, 16: 201-04 (April 1932).

background. Because of the size of the stimuli used, this study might be more applicable to outdoor advertising than to the normal reading situation.

An experiment by Preston, Schwankl, and Tinker[6] investigated the effect of color print and background on the perceptibility of isolated five-letter words seen at a distance. The authors concluded that the greater the brightness contrast between figure and background, the greater the legibility.

A comprehensive investigation of color combinations of print and background in relation to speed-of-reading was undertaken by Tinker and Paterson.[7] The authors applied their speed-of-reading technique to test 11 combinations of ink and paper. The results, which can be seen in Table I, are in terms of percentage differences between black on white versus each of the other ten color combinations. The authors suggest that brightness contrast, or luminosity, is the determining factor in the legibility of

---

6 Katherine Preston, Howard P. Schwankl, and Miles A. Tinker, "The Effect of Variations in Color of Print and Background on Legibility," Journal of General Psychology, 6: 459-61 (April 1932).

7 Miles A. Tinker and Donald G. Paterson, "Studies of Typographical Factors Influencing Speed of Reading: VII. Variations in Color of Print and Background," Journal of Applied Psychology, 15: 471-79 (October 1931).

the subject combinations; the same combinations used in the study by Preston, Schwankl, and Tinker.[8]

TABLE 1

LEGIBILITY OF COLORED PRINT ON COLORED PAPER

Color Combinations Compared With Standard Black-on-White	Differences* in Per Cent
Black on white (standard)	0.0
Green on white	- 3.0
Blue on white	- 3.4
Black on yellow	- 3.8
Red on yellow	- 4.8
Red on white	- 8.9
Green on red	- 10.6
Orange on black	- 13.5
Orange on white	- 20.9
Red on green	- 39.5
Black on purple	- 51.5

* Minus signifies less legibility than black on white.

Stanton and Burtt[9] studied the influence of tinted papers on speed-of-reading and found that slight differences in color caused no significant differences in mean reading speeds.

---

8 Preston, Schwankl, and Tinker, pp. 459-61.

9 Frank N. Stanton and Harold E. Burtt, "The Influence of Surface and Tint of Paper on the Speed of Reading," *Journal of Applied Psychology*, 19: 683-93 (December 1935).

Ruggles[10] studied the reading rate and pleasingness of five ink colors printed on a controlled yellow stock. He found no significant differences among any of the colors of ink used. He tested black, blue, red, green, and brown. However, as far as pleasingness goes, he found black and blue both were chosen significantly over all other colors--but with no significant difference between those two. Brown was significantly preferred to red and green; red and green were not significantly chosen over one another nor any other color.

Paterson and Tinker,[11] Taylor,[12] and Holmes,[13] in independent studies, all found black on white to be significantly easier and faster to read than white on black.

---

10 Philip K. Ruggles, "An Inquiry into the Legibility and Pleasingness of Five Ink Colors Printed on Yellow Stock," Unpublished M.S. thesis, South Dakota State University (1966).

11 Donald G. Paterson and Miles A. Tinker, "Studies of Typographical Factors Influencing Speed of Reading: VI. Black Type versus White Type," Journal of Applied Psychology, 15: 241-47 (June 1931).

12 Cornelia D. Taylor, "The Relative Legibility of Black and White Print," Journal of Educational Psychology, 25: 561-78 (November 1934).

13 Grace Holmes, "The Relative Legibility of Black Print and White Print," Journal of Applied Psychology, 15: 248-51 (June 1951).

In the speed-of-reading measurements of Tinker and Paterson[14] discussed above, red print on a dark green background was read 39.5 per cent more slowly than black on white. From an eye-movement study, Tinker and Paterson[15] suggest that specific differences in eye-motion patterns underlie this result. Their results showed an increase significant at the .01 level in fixation frequency, pause duration, perception time, and regression time.

Hackman and Tinker[16] undertook an eye-movement study investigating seven color combinations used by Tinker and Paterson in a previous study. They reported significant differences between variations of color combinations when using eye-movement techniques. They found black on yellow to be best in an overall rank-order where the standard black on white was ranked fourth. The authors point out that eye-movement tests help to substantiate speed-of-reading values but do not give the precise discrimination between legibility of color combinations as do speed tests.

---

14 Tinker and Paterson, pp. 471-79.

15 Miles A. Tinker and Donald G. Paterson, "Eye Movements in Reading Black Print on White Background and Red Print on Dark Green Background," American Journal of Psychology, 57: 93-94 (January 1944).

16 R. B. Hackman and Miles A. Tinker, "The Effect of Variations in Color of Print and Background Upon Eye Movements in Reading," American Journal of Optometry and Archives of the American Academy of Optometry, 34: 354-59 (July 1957).

Tinker,[17] in his book Legibility of Print, suggests that as brightness contrast (or luminosity) between print and background becomes progressively greater, printed material can be more quickly perceived. He suggests that the paper background used should have 70 per cent reflectiveness or more, with the corresponding ink having a reflectiveness of 10 per cent. This contrast would be great enough to produce legible copy. Colored print with a tinted paper can be coordinated in such a way as to keep both legibility and pleasingness at a satisfactory level--this point was emphasized by the author.

Luckiesh and Moss[18] found that the visibility of print seemed directly related to the reflectance of the paper.

In Legibility of Print, Tinker points out that many persons unfamiliar with color fail to realize that color contrast and brightness contrast are two different things. For example, red and blue have considerable color contrast but little brightness contrast. He suggests that two shades or two tints will show little brightness contrast.

---

17 Tinker, pp. 128-60.

18 Matthew Luckiesh and Frank K. Moss, "The Visibility and Readability of Print on White and Tinted Papers," Sight-Saving Review, 8: 123-34 (June 1938).

In printing, one should use a shade with a tint. Tinker favors a dark ink on a light background.

Tinker,[19] in his book Bases for Effective Reading, suggests that another factor relevant to the understanding of color legibility is the change in the visual appearance of a color when printed on another color. This becomes obvious by examining the observed effect of the color combinations investigated by Tinker and Paterson.[20] Table 2 shows the 11 color combinations of ink and paper with their observed visual effects.

TABLE 2

COLOR COMBINATIONS OF INK AND PAPER WITH OBSERVED COLOR EFFECTS

Color Combination	Observed Effect
Black on white	Black on light grayish white
Grass green on white	Dark green on light grayish white
Luster blue on white	Dark blue on light grayish white
Black on yellow	Black on yellow
Tulip red on yellow	Light red on yellow
Tulip red on white	Light red on light grayish white
Grass green on red	Dark grayish green on red
Chromium orange on black	Dark lemon yellow on grayish black
Chromium orange on white	Light orange on light grayish white
Tulip red on green	Dark brown on dark green
Black on purple	Black on violet

19 Tinker, pp. 162-66.

20 Tinker and Paterson, pp. 471-79.

Zachrisson,[21] in his book Legibility of Printed Text, ·ites:

> "There is another group of statements which must not be neglected. These are the opinions of typographers. . . . The typographer feels free to select materials in which he has confidence as an artist and experienced technician. It is when he generalizes his individual experiences and principles of approach that he is liable to cause confusion. An example of this is afforded by the statements of Tschichold (1951, 1954). This author claims not only that tinted paper (yellowish-reddish) is superior to white as far as legibility goes, but also states that white paper is harmful and fatiguing to the eyes. There is no evidence to support these statements."

Based on previous investigations, this author chose o experiment with eye-movement techniques. Ruggles'[22] rocedure of studying various ink colors printed on a con- rolled yellow background will serve as the focus of the roposed investigation.

bjectives of the Study

The study had two major objectives. The first was to note if significant differences could be found in the eye-movement patterns for each of five differently colored black, blue, brown, red, and green) reading selections on controlled yellow stock. The second objective was to

---

21 Bror Zachrisson, Studies in the Legibility of Printed Text. Upsala: Almquist and Wiksells Boktryckeri B, 1965, pp. 63-65.

22 Ruggles

note if significant differences could be found in the reading speeds for each of five ink colors on a controlled yellow stock. Thus the following studies will be reported on:

1. An analysis of eye-movement photography in relation to fixation frequency, regression frequency, pause duration, and span of recognition comparing five colors printed on a controlled yellow stock.

2. A comparison of eye-movement photography with a silent reading test in relation to speed-of-reading.

3. The relative reading efficiency of each of the five colors.

From the previous discussion the following null hypotheses can be formulated:*

1. Hypothesis: That the fixation frequency will not vary significantly among the five colors.

2. Hypothesis: That the regression frequency will not vary significantly among the five colors.

3. Hypothesis: That the speed-of-reading results will not differ significantly among the five colors.

---

* Based on color changes prescribed by Ruggles in terms of reflectance.

CHAPTER II

METHODOLOGY OF THE STUDY

Controlled Variables

During the testing period of this study, the following variables were controlled: the stock color, the inks and ink color, the brightness contrast between the ink and stock, the size and face of type, the length and difficulty of material read, and the lighting in the testing area.

Stock Used

Because of the controlling of color and the desire to match the stock used in the Ruggles study, choice of paper was important to this study.

In the Ruggles study, the stock used was Springhill Canary Index, substance 90. The author found it impossible to use the Springhill brand paper and substituted a Canary Index manufactured by the Hammermill Paper Company, substance 90. What is more important than matching brand names is that the Hammermill paper showed identical readings on a densitometer to the paper used by Ruggles. This reflectance test took place in the printing laboratory at South Dakota State University. The test consisted of placing the densitometer on the Ruggles sample and setting that reading at the standard "1." The Hammermill paper's readings were identical to the Springhill paper's readings when repeated five times, over different areas of the paper.

Inks Used

The inks used were manufactured by the Lewis Roberts Company. This was the same brand of ink used by Ruggles. Also, the inks used in this study were of the same trade name and company reference number as the inks used in the Ruggles study. (Table 3 lists the inks used in the study.)

TABLE 3

INKS USED IN THE STUDY TO BE PRINTED ON YELLOW HAMMERMILL INDEX STOCK

Ink (Trade Name)	Company Reference Number
1. Pronto Offset Black	OK 941
2. Pronto Offset Reliance Red	OR 16P
3. Pronto Litho Green	OG 344
4. Pronto Offset Regal Blue	OB 40P
5. Pronto Offset Tableau Brown	ON 57P

Although the printed tests were not run on the same press as in the former study, the author was assured, through consultation with experienced pressmen, of the full covering power of each of the selected inks.

Ink-Stock Luminosity

A third variable controlled was the ink-stock luminosity difference. A densitometer was used to measure the reflectance between the yellow background and each of the five colors of ink. Table 4 shows the ink-stock luminosity difference of the five inks used.

TABLE 4

STOCK REFLECTANCE AND INK ABSORBANCE QUALITIES AS MEASURED BY THE DENSITOMETER

Inks	Stock Reflectance	Ink Absorbance	Difference
Black	93.50%	3.20%	90.30%
Brown	93.30	6.80*	86.50
Blue	93.30	2.95	90.35
Red	93.30	6.90	86.40
Green	93.30	7.00	86.00

*Measured with a white filter.

These readings were compared to readings published by Ruggles, using analysis of variance. The readings were found to be no different from Ruggles' figures.

The greater the difference between stock reflectance and ink absorbance, the greater the contrast between stock and ink. A contrast difference in rank order can be seen in Table 5.

TABLE 5

RANK ORDER OF CONTRAST LUMINOSITY AS MEASURED BY THE DENSITOMETER

Ink Color		Difference
1.	Blue	90.35%
2.	Black	90.30
3.	Brown	86.50
4.	Red	86.40
5.	Green	86.00

It is important to note that the above rank order was identical to the contrast ranking determined by Ruggles. The contrast between ink and stock in this study was arranged manually, by the author, to be identical to that of the Ruggles study. (Samples of stock and inks used appear in Appendix A.)

Type Used

A fourth variable controlled was the type used for the examination material. Copy was set ten-point leaded on a 19-pica line in Garamond light face.

Test Material

A fifth variable controlled was the material used for the reading examination. The composition was set from test selections developed by the Educational Development Laboratories of Huntington, New York. The test selections were categorized for the college-adult level. Test selections were checked by the Flesch readability formula and declared equal in content difficulty, vocabulary level, and reader interest by Educational Development Laboratories. (Copy used for test selections can be found in Appendix A.)

Lighting

A sixth variable, lighting, was controlled by having all reading examinations taken in the same location--the author's living room.

Intervening Variables

Although the above variables were considered to be the most important variables affecting the results of this study, it should be noted that other intervening variables may have had some effect.

Method of Reproduction

Because of the importance of obtaining test selections identical in appearance and contrast to those used by Ruggles, the method of reproduction should be noted.

After the copy was set by Linotype, reproduction proofs were taken to be used as actual test samples. The copy was positioned on 5 1/2" by 8" sheets so as to have a top margin of 5 1/4 picas, a bottom margin of 3 1/4 picas, and side margins of 5 3/4 picas each.

Each color was printed and measured by a densitometer to judge its acceptability. Two sets of examinations (one to be used as a spare) were produced to meet densitometer standards. (Examples of test cards can be found in Appendix A.)

Procedure for the Reading-Eye Examination

Subjects used in the study consisted of students in attendance at South Dakota State University. The working sample consisted of 30 students. A total of 58 subjects were examined, of which 28 had to be rejected on the basis of poor quality photographs.

The instrument used to conduct these tests was an eye-motion camera, the Reading Eye, manufactured by the Educational Development Laboratories of Huntington, New York. (A brief explanation of the operation of the camera can be found in Appendix B.)

The test began by informing the subject that this test was for a research project in printing. Following this, the subject was introduced to the nature of eye movements and eye-movement photography. Next, the subject sat in position and the camera was adjusted for comfort. The subject was given a sample form to read (supplied with the camera) to help acquaint the subject with reading into the camera.

The examination consisted of reading five different selections. Each selection would be of a different color (black, brown, blue, red, and green). The first subject read colors in a sequence of (1) black, (2) brown, (3) blue, (4) green, and (5) red. Following subjects read selections in an order based on a rotational variation of the first sequence so that every sixth subject read the same sequence.

At all times, the subject was told to read for comprehension. Following every selection, test questions were asked to judge the validity of the subject's reading.

Testing Comprehension

A comprehension quiz was given orally by the investigator after each reading selection. The purpose of this quiz was to determine whether the subject was reading all of the words rather than skimming.

It was suggested by Educational Development Laboratories that when selections are read in rapid sequence and less time is available for adjustment, preparation, etc., 60 per cent may prove sufficient comprehension to insure that the subject was reading to the best of his ability.

The quiz served as nothing more than a knock-out device. The result of each quiz was discarded after determining the reading validity of the subject. No subject failed the comprehension quiz. (Samples of the quizzes can be found in Appendix C.)

Eye-Movement Analysis

After each film was developed, six measurements were applied to analyze the results. The measurements were: number of fixations per 100 words, number of regressions per 100 words, average span of recognition, average duration of fixation, rate of reading, and relative reading efficiency.

Fixations

"Fixation or fixation pause refers to that period in reading a line of print during which the eyeball is held stationary for a short time and during which perception takes place. Following one fixation, the eye jumps to a new fixation point. This inter-fixation movement is often called a saccade or saccadic movement, for the eye acts as if it were being thrown or jerked. One set of muscles, termed the agonists, contracts, putting the eye into motion. The eye is brought to a stop when a second set of muscles, the antagonists, contracts, producing a relative equilibrium of forces. The eye is never completely still, and never moves with absolute precision; however, it is stationary enough to allow perception to take place. The eye proceeds to the end of the line of print in a series of eye stops, then sweeps back in another saccadic movement to the beginning of the next line of print. This movement is commonly referred to as the return sweep."[1]

The majority of people are relatively unaware of the vast number of fixations they make in proportion to the words read. For instance, the average adult reading a ten-word line will tend to make from eight to ten fixations. A superior reader will make perhaps five, while a child in elementary school will fixate from 13 to 17 times in ten words. The word-by-word reader does not make one eye stop per word, but usually makes two or more. As readers, we are unaware of this amount of activity because of the rapidity with which eye movements take place, the subtlety of the activity involved, and our lack of direct, conscious control.

Regressions

"Regressions, or reverse fixations, are those fixations immediately following a right-to-left saccade or movement. The causes of regressions stem from visual acuity or vergence problems, perceptual inadequacies, and

---

1 Stanford E. Taylor, Eye-Movement Photography with the Reading Eye, (Educational Development Laboratories, Huntington, New York, 1960), p. 36.

lack of sufficient interpretive or organizational ability. However, as components of a person's Fundamental Reading Skill, regressions can be classified into two types: Those that are habitual, and those that are caused by the difficulties of the moment."[2]

Span of Recognition

"The span of recognition refers to the amount of words or word-parts perceived during a fixation or eye pause. It does not refer to the amount of material impinging on the eye but rather to the amount the reader recognizes and can deal with interpretively. In reading, the 'perceptions' are so interrelated and interdependent that it is unrealistic to think of span as a measurement during an isolated seeing situation. Rather, when considering a person's visual intake in reading, we must look to his performance throughout a selection as providing a more typical reflection of his visual intake. In eye-movement photography, therefore, we compute the average span of recognition, fully realizing that there is undoubtedly some variation from fixation to fixation and from line to line in what the reader apprehends. This variation, however, judging from the usual reading patterns of most readers, is not great,

2 Taylor, p. 38

for most readers tend to maintain their characteristic number of fixations per line throughout a selection, and within any given line do not fluctuate significantly in the extent of the saccadic movement."[3]

The average span of recognition, for a college-level reader was estimated by the Educational Development Laboratories to be 1.11 words or 2.3 picas (reading a 19-pica line).

Duration of Fixation

"The duration of fixation refers to the length of time a reader's eyes pause during a fixation. In eye-movement photography, we use the average duration of fixation. Rather than isolate the duration from the total reading activity, we concern ourselves with the average duration computed from the reader's performance over the entire selection.

"It should be noted that in eye-movement computation, the length of time required for the inter-fixational movements and return sweeps is included as part of the fixation time or reading time; consequently, the average duration of fixation will include the time measured for saccadic movement. This, however, does not detract from the usefulness of the final figure, since the saccadic

3 Taylor, p. 40

movement occupies such a slight amount of time and does not shorten significantly with maturation."[4]

Rate

Rate, in the study, is based on X words read per minute, an average measurement, and need not be explained since it is usually included in most reading tests.

Relative Reading Efficiency

Relative reading efficiency is a calculation introduced in order to arrive at a more objective numerical indication of reading effort. For the study, this measurement ranked the selections, within each sequence, according to an expression of efficiency. The formula is as follows: Efficiency = Rate (w.p.m.)/Fixations per 100 words + Regressions per 100 words.

---

4 Taylor, p. 42

CHAPTER III

FINDINGS

To simplify presentation and understanding of the results obtained in the investigation, the study has been divided into six components. These components are fixations, regressions, speed-of-reading, average duration of fixation, average span of recognition, and overall reading efficiency.

Analysis of variance revealed that, of the five colors (blue, black, green, red, and brown) studied, significant differences occurred for fixations and regressions.

I. Fixations

This experiment showed that selections printed in both blue and black were significantly different from selections printed in green, red, and brown. There was no significant difference between any other combination of colors. That is, the blue selection was not significantly different from the black selection nor were there significant differences among the green, red or brown selections in relation to fixation frequency.

In order to keep the number of tables to a minimum, only tables of tests having significant differences are represented (Tables 6 through 12).

TABLE 6

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES IN COLORS OF INKS IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	4	4,326.77	1,081.69	
Within Means	145	39,056.91	269.35	4.01**
Totals	149	43,383.68		

* p .05
** p .01

TABLE 7

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND GREEN IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	1,560.60	1,560.60	
Within Means	58	15,906.40	274.24	5.68*
Totals	59	17,467.00		

* p .05
** p .01

TABLE 8

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND RED IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	1,972.27	1,972.27	
Within Means	58	14,543.67	250.75	7.86**
Totals	59	16,515.94		

* p .05
** p .01

TABLE 9

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND BROWN IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	2,343.77	2,343.77	
Within Means	58	14,471.88	249.51	9.39**
Totals	59	16,815.67		

* p .05
** p .01

TABLE 10

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLACK AND GREEN IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	1,244.15	1,244.15	
Within Means	58	15,781.70	272.09	4.57*
Totals	59	17,025.85		

* p .05
** p .01

TABLE 11

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLACK AND RED IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	1,612.02	1,612.02	
Within Means	58	14,418.97	248.60	6.44*
Totals	59	16,030.99		

* p .05
** p .01

TABLE 12

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLACK AND BROWN IN RELATION TO FIXATION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	1,949.40	1,949.40	
Within Means	58	14,348.20	247.38	7.88**
Totals	59	16,297.60		

* p .05
** p .01

II. Regressions

This experiment showed that the test selection printed in blue differed significantly from the selections printed in green, red, and brown. The selection printed in black was found to be significantly different from the selections printed in red and brown. There was no significant difference between any other combination of colors. That is, the blue selection was not significantly different from the black selection; the black selection was not significantly different from the green selection; nor were there significant differences among the green, red or brown selections in relation to regression. Only tables of tests having a significant difference are represented (Tables 13 through 18).

TABLE 13

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES IN COLORS OF INKS IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	4	184.42	46.105	4.238**
Within Means	145	1,577.24	10.877	
Totals	149	1,761.66		

* p .05
** p .01

TABLE 14

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND GREEN IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	56.06	56.06	
Within Means	58	610.54	10.52	5.32*
Totals	59	666.60		

* p .05
** p .01

TABLE 15

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND RED IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	86.40	86.40	
Within Means	58	457.54	7.88	10.96**
Totals	59	543.94		

* p .05
** p .01

TABLE 16

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLUE AND BROWN IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	117.61	171.61	
Within Means	58	586.14	10.10	11.64**
Totals	59	703.75		

* p .05
** p .01

TABLE 17

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLACK AND RED IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	59.97	59.97	
Within Means	58	582.77	10.04	5.97*
Totals	59	642.74		

* p .05
** p .01

TABLE 18

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES BETWEEN BLACK AND BROWN IN RELATION TO REGRESSION FREQUENCY

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	1	86.40	86.40	
Within Means	58	711.34	12.26	7.04*
Totals	59	797.74		

* p .05
** p .01

III. Speed-of-Reading

Analysis of variance revealed that, of the five colors (blue, black, green, red, and brown) studied, no significant differences occurred among the mean reading speeds. This can be seen in Table 19.

TABLE 19

ANALYSIS OF VARIANCE METHOD USED TO NOTE VARIANCES IN COLORS OF INKS IN RELATION TO SPEED-OF-READING

Source of Variance	df	Sum of Squares	Mean Squares	F
Among Means	4	56,971.11	14,242.77	
Within Means	145	1,010,708.67	6,970.40	2.004
Totals	149	1,067,679.78		

* p .05
** p .01

As noted in the table, the F (of the five colors) was 2.004. In order to be significant at the .05 level, an F of 2.37 was necessary.

As can be seen in Table 20, the greatest difference among mean reading speeds was found between the blue selection and the brown selection. Blue was read faster than brown by 39.50 words per minute.

TABLE 20

DIFFERENCES IN MEAN READING SPEEDS AS MEASURED FROM THE CONTROL BLUE

Color of Ink	Average Rate Per Minute	Difference
Blue	334.33	00.00
Black	334.00	00.33
Green	316.36	17.97
Red	301.40	32.93
Brown	294.83	39.50

IV. Average Duration of Fixation

This experiment showed that duration of fixation changed slightly within the test selections studied. The greatest difference (that between the black and brown selections) was only 0.01 seconds. Table 21 shows differences in average duration of the five colors tested.

TABLE 21

DIFFERENCES IN AVERAGE DURATION TIME AS MEASURED FROM THE CONTROL BLUE

Color of Ink	Average Duration Time In Seconds	Difference
Blue	0.276	0.000
Black	0.277	+ 0.001
Green	0.274	- 0.002
Red	0.269	- 0.007
Brown	0.267	- 0.009

V. Span of Recognition

This study showed that the span of recognition varied only slightly within the selections tested. The greatest difference of span of recognition, in terms of picas, was 0.47 picas; in terms of words, the greatest difference was 0.249 words. Table 22 shows the differences in span of recognition within the selections tested.

TABLE 22

DIFFERENCES IN SPAN OF RECOGNITION AS MEASURED FROM THE CONTROL BLUE

Color of Ink	Span of Recognition in: Words	Picas	Difference: Words	Picas
Blue	1.602	2.92	0.000	0.00
Black	1.569	2.87	- 0.033	- 0.05
Green	1.405	2.52	- 0.197	- 0.40
Red	1.371	2.48	- 0.221	- 0.44
Brown	1.353	2.45	- 0.249	- 0.47

VI. Efficiency Rank

The experiment revealed that in terms of relative reading efficiency the blue selection ranked first, the black second, the green third, the red fourth, and the brown last. Table 23 shows how each individual subject read each of the five colored test selections in relation to relative reading efficiency. Table 23 also shows the total points scored by each color (the more points, the higher the rank).

TABLE 23

EFFICIENCY RANK OF COLOR PER SUBJECT

Subject	Blue	Black	Green	Red	Brown
1	2	1	5	4	3
2	2	1	3	5	4
3	2	1	5	4	3
4	2	1	5	4	3
5	1	4	3	2	5
6	2	1	3	5	4
7	1	2	5	4	3
8	2	1	4	5	3
9	1	2	4	5	3
10	3	1	5	4	2
11	1	2	5	3	4
12	1	2	3	5	4
13	2	1	3	4	5
14	1	3	2	4	5
15	3	4	1	2	5
16	1	2	4	3	5
17	1	2	4	3	5
18	2	1	3	5	4
19	2	1	3	4	5
20	1	2	4	3	5
21	1	2	3	4	5
22	2	1	3	4	5
23	2	1	3	4	5
24	2	1	3	5	4
25	1	2	4	5	3
26	1	3	2	4	5
27	1	2	3	5	4
28	1	2	3	5	4
29	1	2	5	4	3
30	1	2	3	4	5
Total Score	134	127	74	58	57

CHAPTER IV

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDY

Summary

The purpose of this study was to compare five differently colored reading selections in terms of fixations, regressions, speed of reading, average duration of fixation, average span of recognition, and relative reading efficiency. The following ink colors were tested in the study: blue, black, green, red, and brown. Each color was printed on a controlled yellow background.

The apparatus used in the investigation was an eye-movement camera developed by the Educational Development Laboratories. The experimenter photographed the eye movements of 30 college-level readers. It was discovered that some subjects found reading via the camera uncomfortable and distracting. Photographs of the eye movements of "uncomfortable" readers were discarded because excessive head-movement caused their photographs to be uninterpretable.

After the subjects had been examined and their results tabulated, the data were subjected to statistical analysis. Analysis of variance revealed significant differences among the five (blue, black, green, red, and brown) test selections in relation to fixations. The study showed that the blue selection was significantly different from the green, red, and brown selections. The black selection was also found to be significantly different from the green, red, and brown selections. No other significant differences occurred. It is well to note that the difference between the selection read with the fewest fixations (blue, 1947) and the selection read with the most fixations (brown, 2322) was 375 fixations. This represents an average of 12.3 more fixations per 100 words.

Analysis of variance also revealed significant differences among the five test selections in relation to regressions. The experiment showed that the blue selection was significantly different from the green, red, and brown selections. The black selection was also found to be significantly different from the red and brown selections. No other significant differences occurred. The difference between the selection read with the fewest regressions (blue, 115) and the selection read with the most regressions (brown, 199) was 84 regressions. This represents an average of 2.8 more regressions per 100 words.

Like the Ruggles study, no significant difference was found among the mean reading speeds of the five test selections. The blue selection was read the fastest, followed by the black, green, red, and brown selections, respectively. This was the same rank order reported in the Ruggles study. The greatest difference, in reading rate, was between the blue selection and the brown selection. This difference was 39.50 words per minute.

The experiment showed that the average duration of fixation was affected only slightly by the changes in color. The greatest difference in duration pause (between the black and brown selections) was 0.01 second.

The average span of recognition, also, was only slightly affected by the change of colors of the test selections. In terms of picas, the difference between the selection read with the largest span of recognition and the selection read with the smallest span of recognition was 0.47 picas. In terms of words, (as measured by the Educational Development Laboratories) this difference is 0.249 words.

When the test selections were compared in relation to relative reading efficiency, the blue selection was ranked first, followed by the black, green, red, and brown selections, respectively. It should be noted that the term "relative efficiency" is concerned with reading rate, fixations and regressions.

Conclusions

From a relative-efficiency point of view, one can conclude that blue and black are superior in legibility to green, red, and brown when printed on a controlled yellow background. This is not to say that green, red, and brown are less legible than blue or black, only less efficient.

The results of this study are in line with those of many previous experiments and undeniably support the fact that luminosity is an important factor in legibility. This fact is supported by the correlation between the luminosity rank of the various colors and the relative efficiency rank of the colors. It is well to note that the luminosity readings of the five colors can be described as follows: both the blue and black colors were at least measurably greater than the green, red, and brown; the blue and the black colors were relatively equal; the green, red, and brown colors were relatively equal. This description is indicative of the final efficiency ranking.

From the significant differences found in fixations, the null hypothesis 1. can be rejected. One can conclude that this component of the reading process is greatly dependent upon luminosity for efficiency. The blue and black selections, which showed the greatest luminosity, were read with significantly fewer fixations than were the green, red, or brown selections. The fact that where no appreciable difference in luminosity existed, no significant difference in fixations occurred, supports the conclusion that luminosity, or brightness contrast, is an important factor in legibility.

When considering the significant differences found in regressions, one can reject null hypothesis 2. Again, the blue and black selections (which showed the greatest luminosity) were read with significantly fewer regressions than were the green, red, and brown selections. Also, where no appreciable difference in luminosity existed, no significant difference in regressions occurred.

Although no significant differences were reported, in relation to speed-of-reading, the slight differences which did occur reinforce the conclusion that luminosity is an important factor in legibility and the null hypothesis 3. can be accepted. The blue and black selections were both read measurably faster than the green, red, or brown selections. It is the author's opinion that the luminosity differences reported for the five test selections affected these changes in reading rates. From this, one can conclude that if the luminosity differences would be increased, so would the differences among the reading rates. It must be conceded that the green selection, although ranked fifth in luminosity, ranked third in speed-of-reading. This deviation can be concluded to be a chance happening, pending more sophisticated research.

Unlike fixations or regressions, duration remained remarkably constant among the five test selections. Based on the nature of eye-movements, this finding was to be expected. It would appear that the duration time could not be significantly changed unless the legibility of the reading material was significantly changed. Of course, this is a postulation on the part of the author.

A similar conclusion could be reached concerning the span of recognition. Like duration, the span of recognition remained remarkably constant among the five test selections.

These two components, duration and span of recognition, can be considered together since the average span is a mathematical calculation obtained by dividing words read by the number of fixations, and the average duration is a mathematical calculation obtained by dividing the total reading time (in seconds) by the number of fixations.

Because there were no significant differences in reading rates, average duration, or average span, but were significant differences in fixations and regressions, one can conclude that fixations and regressions were more readily affected by the variations in color and luminosity than were the other measured components.

The purpose of this study was to note the effects of changes in color on legibility. However, based on the reported data, the author must join that group of people who doubt that it is the color as such which is the main factor in determining the legibility of a piece of printing.

Instead, the author must conclude that the brightness contrast, or luminosity, produced by printing one color over another is, in fact, a more significant factor of legibility than the color itself.

It has been pointed out that the use of color, in commercial printing, is increasing. From the results of this study, one can conceive of the use of almost any combination of print and background that maintains satisfactory luminosity characteristics. This has been demonstrated, in a small way, by the five color combinations used in this study.

It is the author's opinion that luminosity is an important factor in legibility; however, luminosity is not the only factor in legibility. Other variables have been investigated and found to be significant factors when considering legibility. Luminosity, in respect to color, serves as a factor to be controlled if one wishes to reach a given level of legibility.

The author believes this study has shown the following ink colors on a yellow background, by measurement of relative reading efficiency, to be placed in rank order as follows:

1. Blue on yellow
2. Black on yellow
3. Green on yellow
4. Red on yellow
5. Brown on yellow

This rank order matches the rank order based on luminosity except in the positions of green and brown. Green was ranked fifth in luminosity and brown third; this is the exact opposite of their rank in relative efficiency. The author must conclude that the effects of intervening variables and of pure chance are responsible for this discrepancy.

Recommendations for Further Study

The author would like to recommend that a study be undertaken to replicate this investigation in order to substantiate and refine results obtained in this study. The author believes this study to be valid; however, replication and criticism of this study can shed more light on the subject.

Another study, of the same color combinations, using perception at a distance as a criterion could add more insight to previous research and perhaps help resolve the green-brown reversal of this study.

BIBLIOGRAPHY

Griffing, Harold, and Shepherd I. Franz. "On the Conditions of Fatigue in Reading," Psychological Review, 3: 513-30 (September 1896).

Hackman, R. B., and Miles A. Tinker. "The Effect of Variations in Color of Print and Background Upon Eye Movements in Reading," American Journal of Optometry and Archives of the American Academy of Optometry, 34: 354-59 (July 1957).

Holmes, Grace. "The Relative Legibility of Black Print and White Print," Journal of Applied Psychology, 15: 248-51 (June 1951).

Luckiesh, Matthew, and Frank K. Moss. "The Visibility and Readability of Print on White and Tinted Papers," Sight-Saving Review, 8: 123-34 (June 1938).

Miyake, Ruth, Jack W. Dunlap, and Edward Cureton. "The Comparative Legibility of Black and Colored Numbers on Colored and Black Backgrounds," Journal of General Psychology, 3: 340-43 (April 1930).

Paterson, Donald G., and Miles A. Tinker. "Studies of Typographical Factors Influencing Speed of Reading: VI. Black Type versus White Type," Journal of Applied Psychology, 15: 241-47 (June 1931).

Preston, Katherine, Howard P. Schwankl, and Miles A. Tinker. "The Effect of Variations in Color of Print and Background on Legibility," Journal of General Psychology, 6: 459-61 (April 1932).

Ruggles, Philip K. "An Inquiry into the Legibility and Pleasingness of Five Ink Colors Printed on Yellow Stock," Unpublished M.S. thesis, South Dakota State University (1966).

Stanton, Frank N., and Harold E. Burtt. "The Influence of Surface and Tint of Paper on the Speed of Reading," Journal of Applied Psychology, 19: 683-93 (December 1935).

Sumner, F. C. "Influence of Color on Legibility of Copy," Journal of Applied Psychology, 16: 201-04 (April 1932).

Taylor, Cornelia D. "The Relative Legibility of Black and White Print," Journal of Educational Psychology, 25: 561-78 (November 1934).

Taylor, Stanford E. Eye-Movement Photography with the Reading Eye, Educational Development Laboratories, Huntington, New York (1960).

Tinker, Miles A., and Donald G. Paterson. "Studies of Typographical Factors Influencing Speed of Reading: VII. Variations in Color of Print and Background," Journal of Applied Psychology, 15: 471-79 (October 1931).

Tinker, Miles A. "The Effect of Color on Visual Apprehension and Perception," Genetic Psychological Monographs, 11: 61-136 (February 1932).

Tinker, Miles A., and Donald G. Paterson. "Eye Movements in Reading Black Print on White Background and Red Print on Dark Green Background," American Journal of Psychology, 57: 93-94 (January 1944).

Tinker, Miles A. Legibility of Print, Chapter 9. Color of Print and Background. Ames, Iowa: Iowa State University Press, 1963, pp. 128-60.

Tinker, Miles A. Bases for Effective Reading. Minneapolis: University of Minnesota Press, 1965, pp. 162-66.

Zachrisson, Bror. Studies in the Legibility of Printed Text. Upsala: Almquist and Wiksells Boktryckeri AB, 1965, pp. 63-65.

APPENDICES

APPENDIX A

SAMPLES OF STOCK, INKS, AND COPY USED IN THIS STUDY

Test Selection 1: Blue Ink on Yellow Hammermill Index.

Test Selection 2: Black Ink on Yellow Hammermill Index.

For centuries, all clothes were made by hand. Elias Howe, observing his wife sew clothes for their children, started thinking. By 1845, he had designed a machine for sewing and succeeded in patenting it. The idea that made Howe's sewing machine practical was carrying the thread in the point of the needle instead of the head. Americans showed no interest in Howe's machine, so he departed for England. There it proved its value in a corset factory. When he came home, he discovered copies of his machine being manufactured and sold. Since Howe had the patents, he sued the manufacturers and was able to win every case. As a result he became a millionaire.

Test Selection 3: Green Ink on Yellow Hammermill Index.

The people of Hawaii enjoy all water sports. One of the most exciting is riding a surfboard over the rolling waves. A surfboard is made of wood that can be highly polished to glide easily through the water. Surfboards look like solid pieces of wood that are usually hollow inside, and light and easy to carry. The boards range between six and twelve feet long. The length is chosen according to the rider's weight and the type of surf to be ridden. The men who teach visitors this sport are called "surfers." With nothing to hold on to, it is difficult to raise yourself to a standing position. Skilled surfboard riders can go thirty miles an hour.

Test Selection 4: Red Ink on Yellow Hammermill Index.

Eskimos use a one-man boat the kayak. Kayaks are made of animal skin stretched over a frame of bone. This makes them very light and easily portable. The skin covers the kayak completely except for a small hole for the paddler. The paddler buttons a flap tightly around his waist to make the kayak watertight. He can flip the boat over and quickly surface again. Many times the paddler will turn the boat over on purpose, because the bottom can better stand the shock of heavy waves. When an Eskimo boy is twelve years old, his father trains him in the secrets of balancing this tricky craft. The hardest job is getting in and out.

Test Selection 5: Brown Ink on Yellow Hammermill Index.

The American pioneer's life depended on his gun. Before the 1840's, men relied on single shot rifles, and slow loading cost many lives during Indian raids. Samuel Colt was fascinated with guns in his youth. While working on board ship, Colt whittled a model of a "revolver" which could shoot five times without re-loading. It is said that the ship's wheel was the inspiration for the revolving shell chamber. His first factory made many five-shooters but it failed due to poor manufacturing methods. At the start of the war with Mexico, the U. S. Army ordered one thousand revolvers. It was then that the six-shooter was manufactured. The six-shooter was called "the gun that won the west."

APPENDIX B

QUIZ QUESTIONS USED IN THE STUDY (TRUE - FALSE)

Test Selection (Blue)

1. The people of Hawaii enjoy riding surfboards.
2. The rolling waves make surfboard riding dangerous.
3. Surfboards are made of highly polished wood.
4. Surfboards are usually hollow inside.
5. They are light and easy to carry.
6. The boards range up to sixteen feet in length.
7. The length is chosen according to the rider's height.
8. Men who teach this sport are canned "boarders."
9. It is difficult to rise to a standing position on a surfboard.
10. A skilled rider can do thirty miles an hour.

Test Selection (Black)

1. Elias Howe began to work on a sewing machine after watching his wife sew clothes.
2. By 1845, he designed a machine for sewing.
3. He was successful in patenting his idea.
4. Howe's idea was to carry the thread in the point of the needle.
5. His machine was an immediate success in America.
6. Howe took his machine to France.
7. It was first successfully used in a corset factory.
8. American manufacturers began to copy Howe's machine.
9. Howe lost all of his lawsuits against these manufacturers.
10. Howe died in poverty.

Test Selection (Green)

1. Clarence Darrow gained his fame as a criminal lawyer.
2. He began his career as a patent attorney.
3. Defending a labor leader caused him to lose his position in a corporation.
4. He was opposed to capital punishment.
5. Darrow defended a hundred persons charged with murder.
6. Only one of his clients received the death penalty.
7. In 1925, he unsuccessfully defended a Tennessee teacher.

8. The teacher was charged with illegally teaching evolution.
9. His defense caused many states to pass laws prohibiting the teaching of evolution.
10. Darrow wrote books on crime.

Test Selection (Red)

1. The Eskimo kayak holds one person.
2. The frame of the kayak is made of wood.
3. The kayak is covered with animal skin.
4. Kayaks are light and portable.
5. The paddler buttons a flap around his neck to keep out the cold wind.
6. The paddler often turns the boat over to avoid being seen by his prey.
7. The paddler may turn the boat over to take heavy waves.
8. An Eskimo boy learns to use a kayak when he becomes ten years old.
9. A kayak is easy to balance.
10. The hardest job is getting in and out of the kayak.

Test Selection (Brown)

1. Before the 1840's, all guns were of the single shot type.
2. The main weakness of early rifles was slow loading.
3. Samuel Colt was afraid of guns when he was young.
4. Colt was working on board ship when he started on his invention.
5. Colt's first revolver could shoot five times without reloading.
6. It is said that the revolving shell chamber was inspired by the ship's compass.
7. Colt's first factory was a high success.
8. The six-shooter was developed at the time of the Mexican War.
9. The Army placed an order with Colt for two thousand revolvers.
10. The six-shooter was called the "gun that won the West."

APPENDIX C

The subject sits, placing his chin on the chinrest and his forehead against headrest pads. The head steadiers are swung into position against his head. As the subject reads the test selection held in test selection holder, illuminated by reading light, recording lights cause beads of light to form on the cornea of his eyes. These beads of light pass through telescoping lenses to a mirror from which they are deflected upwards to a reflex aperture for alignment and focusing or downwards to be recorded on film. To record, reflex aperture door is closed, recording lights dim, and film moves at a continuous rate from film supply spool by the recording aperture and into the take-up magazine. At the completion of each photograph, the I.D. marker bearing the subject's initials is inserted into the I.D. marker entrance, and the initials are flashed onto the graph electronically.

APPENDIX D

EXAMPLE OF ANALYSIS OF VARIANCE METHOD USED IN THIS STUDY

Fixations

A. Computation of Sums of Squares

Step 1. Correction Term (C): $\frac{(10793)^2}{150} = 776,592.32$

$$C = \frac{(\Sigma X)^2}{N}$$

Step 2. Total sum of squares:

```
 188454
 183759          819976.00
 179366        - 776592.32
 132101           43383.68
 136296
 ------
 819976
```

$$SSt = X^2 - C$$

Step 3. Sum of Squares among means:

```
 3790809
 3920400
 5076009
 5248681
 5391684
 --------
23427583
```

23427583/30 = 780919.43

```
  780919.43
- 776592.66
    4326.77
```

$$SSm = \frac{(\Sigma X_1)^2}{K_1} + \frac{(\Sigma Xn)^2}{Kn} - C$$

Step 4. Sum of Squares within groups:

```
  43383.68
-  4326.77
  39056.91
```

$$SSw = SSt - SSm$$

B. Analysis of Variance

Source	df	SS	MS (V)	F
Among Ms	4	4326.77	1081.69	4.01**
Within Groups	145	39056.91	269.35	
Totals	149	43383.68		

4/145 df; F = 1081.69/269.35 = 4.01**

 * p .05
** p .01