1999

The effects of color contrast on performance of the WAIS-R digit symbol subtest

Wendell S. Francke

The Effects of Color Contrast on Performance of the WAIS-R Digit Symbol Subtest

by

Wendell S. Francke

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of

Master of Arts

in

Psychology

Marshall University Graduate College

1999

Master of Arts Thesis

of

Wendell S. Francke

Approved:

Thesis Committee

Major Professor Del Lawhon

Del Lawhon, Ed. D.

Stephen O'Keefe

Stephen O'Keefe, Ph. D.

Teresa Eagle

Teresa R. Eagle Ed. D.

Marshall University Graduate College

1999

Abstract

Color contrast has been shown to aid in visual search tasks using electronic displays, while the research regarding the usefulness of color contrast in aiding visual search using a paper medium is mixed. The present study questions whether subjects' performance will improve on a paper task where the search target is in high color contrast when compared with a task where the target color does not differ from the rest of the search field.

Thirty-nine adults with normal vision were administered two forms of the WAIS-R digit symbol subtest, one with low chromatic contrast and one with high chromatic contrast, in a within-subjects design. No significant difference was found in performance on the two tasks. Explanations offered for these results include the effects of surround luminance, contrast of saturation, and short-term visual memory.

The Effects of Color Contrast on Performance of the WAIS-R Digit Symbol Subtest

Visual search is a component of problem solving. Most tasks require obtaining information from outside of the central nervous system as part of information processing. Some tests of cognitive ability call for obtaining and processing information as part of their ability assessment. The question being addressed in the current study is: 'Is there a relationship between the degree of color contrast of key stimuli and human performance?' Color contrast is the comparison of chromatic wavelengths or hue. Some examples of hue comparisons are green compared to yellow and red compared to blue. Hue is the term used to differentiate the various wavelength components of the visible spectrum (e.g. violet, blue, green, yellow, orange, and red).

The relationship between human performance and the degree of color contrast of target and distractor stimuli on electronic displays is empirically established. In a study by Nagy and Sanchez (1990) human performance improved in a regular fashion with increasing differences of hue of target cues in visual electronic display search trials. Carter and Carter (1988) also found color contrast on electronic display to help people locate information. Examples include related words in a piece of writing, iso-contours on a map and symbols representing aircraft at the same altitude and the deployment of friendly, hostile, or neutral forces on a military situation display. In visual searches with color, human performance improves linearly with increased contrast of hue between distractors and targets (Carter, 1982). These studies all support the hypothesis that color contrast aids visual search in electronic displays.

When considering mediums other than electronic displays, the research is less clear. In the low vision literature, color is commonly believed to aid human performance. Programs and program design for low vision persons routinely operate on color contrast of hue. Lombard and Reidel (1978) observed improved human performance with color contrast in learning disabled children. Lombard and Reidel were analyzing the factor structure on the WISC and WISC-R with learning disabled populations. In their other analyses they discovered a significant increase in performance for a color contrast (red-blue) version of the coding subtest in the WISC-R versus the achromatic (black-white) version in the WISC.

The electronic medium differs from the paper medium in that the observer's gaze falls on a source of light emanating from a computer screen, instead of light reflected from a surface. There may be a relationship between the degree of color contrast of key stimuli and human performance on paper and ink tasks involving visual search. Visual search is needed when the solution of a problem depends on the visual information available (Schweizer, 1998).

A few studies of color and achromatic color with a paper medium are available in the body of literature. McBrayer (1992) compared the difference between chromatic and achromatic presentation of the Picture Arrangement and Picture Completion subtests on the WISC-III. However, she failed to find a significant difference between the chromatic and achromatic tests with normal subjects. She attributed the lack of significant findings to methodological issues. Similarly, Jones (1976) hypothesized that the addition of color to the Picture Arrangement subtest of the WISC-R would decrease testing time and increase scaled scores as compared to the black-white version. Subjects were 3rd and 4th grade children; Jones found a small statistically significant increase in the scaled scores and a decrease in testing time for the color version.

In summary, in electronic displays, color contrast has been repeatedly shown to increase human performance on a visual task with normal adult subjects (Carter, 1982; Carter & Carter, 1988; Nagy and Sanchez, 1990). Carter and Carter (1988) concluded that color may improve performance in a number of mediums, and this is commonly used as a tool in working with low-vision populations (Miles, Cook, Huertas, & Lyon, 1984). Thus far, mixed evidence has been found for the usefulness of color in a paper medium (Jones, 1976; Lombard & Reidel, 1978; McBrayer, 1992). A well-controlled study of color contrast on a paper medium with a normal adult population has yet to be done. In the present study it is hypothesized that subjects will perform significantly better on a high contrast (red-blue) version of the WAIS-R digit symbol subtest than on a low contrast (blue only) version.

Method

Subjects

Subjects were 43 adults aged 25 - 65. Data from four subjects were dropped due to self-reported color blindness. Of the 39 subjects included in the study 28 were females and 11 males. Six percent of the subjects reported completing high school, 10% reported some college, 36% had college degrees. Post college education was as follows: 33.3% had attended graduate courses, 12.8% had a Master's degree, 2.6% had a Doctoral degree. All subjects included in the study reported normal vision.

Procedure

Subjects first gave informed consent to participate in the study and filled out demographic data forms. The experimenter then presented subjects with both high-contrast and low-contrast versions of the test. Presentation of the two forms of the paper task was counterbalanced to control for practice effects.

Instruments

Two versions of the WAIS-R digit symbol subtest were used. The published form was altered in order to administer two levels of the independent variable (difference in chromatic wavelength). For one form the entire test was printed in blue only (low chromatic contrast) while in the other form the symbols in the key were printed in red and the remainder of the test was printed in blue (high chromatic contrast). Thus the perceptual attribute of hue was manipulated. Saturation and lightness were held constant. The reliability coefficients for the digit symbol subtest as administered in the WAIS-R vary from .84 to .86 for the 20-40 age range (Wechsler, 1981) and from .84 to \B for the 40-65 age range. The reliability and validity of the altered version of this subtest is unknown.

The task required subjects to locate information and compare or refer to information already available. They needed to find a symbol that corresponded to a number. Then, they would write the symbol below the number and continue to the adjacent number. The subjects had a fixed amount of time to complete the task. The search format consisted of a key, sample items, and a response area printed on paper.

Results

In order to test the hypothesis that human performance will improve when the color contrast is at its highest value (red-blue) and ANOVA was performed. The analysis revealed no significant difference between the high contrast and low contrast forms of WAIS-R digit symbol subtest ($F_{(1, 38)} = .03$, $p > .05$). The group means are similar. For the high level of contrast, the mean was 67.6 and the standard deviation was 14.5. For the group which received the no contrast version, the mean was 67.8 and the standard deviation was 13.7. Thus, the hypothesis that human performance will improve when the color contrast is at its highest value was not supported.

Discussion

No significant difference was found between scores on low contrast and high contrast versions of the WAIS-R digit symbol subtest. Therefore, in this study, the findings fail to retain the hypothesis that subjects' performance will improve when the color contrast is at its highest value. There are several possible explanations for this result. First, it may be that color contrast may not be important in a visual search task on paper medium. It is possible that light reflected from a surface (paper medium) is not as sensitive to color contrast as light emitted from a surface (electronic medium). The other literature, in a less systematic approach of color contrast is mixed on the conclusion that color does not contribute to performance. Jones (1976) found color a significant factor while McBrayer (1992) did not find an impact for color. Jones (1976) when he discusses the limitations of his paper, points out that hue and lightness were not controlled. A more probable conclusion may be that there are other factors at play in the paper medium which have not been well controlled for such as hue, saturation, lightness and even qualities of the subject.

If one were to consider the perceptible attributes of color as salient variables, then interesting categories arise when comparing studies which manipulate chromatic and achromatic formats. Jones' (1976) study could no longer be compared to Husband's (1996) and McBrayer's (1992) studies, because we do not know what colors Jones used. McBrayer's and Husband's studies can be compared only to a point. Their use of the WISC-III colored subtests were uniform. However, we do not know how Husband created the black and white format. McBrayer noted in her limitations that she lost key stimuli in changing from color to black and white format. Another aspect of contrast may need to be considered. Saturation is the concentration of wavelength or amount of pigment. Difference in wavelength is only one variance. Differences in the amount of wavelength are another. Saturation, an aspect of color contrast, dilutes or intensifies the perception of hue. Saturation refers to the degree to which a color differs from a black, white or gray surface of the same lightness (Arditi & Knoblauch, 1996; Cooper, 1985). Slate blue and deep blue provide an example. Deep blue has the greatest concentration of wavelength. Slate blue is a desaturated color as it is similar to gray (Arditi, 1997; Cooper, 1985).

Additionally, methodological limitations of the present study may have suppressed any significant findings. First, short-term memory may have inhibited the on-going visual search in the present study. Performance on the WAIS-R digit symbol is aided by short-term memory for the symbols (Sattler, 1988). Once the digits and the numbers to which they correspond were memorized, reliance on a visual search to perform the task stopped. The color format may have enhanced the visual recall effect (Petry, 1989).

In the future, a search task could be used to eliminate the threat of short-term memory inhibiting the search. Raven's Matrix may provide such a search task. A benefit for using Raven's Matrix is its correlation to intelligence tests (Sattler, 1988). It is a nonverbal test of reasoning ability and does not involve short-term memory. Color contrast may aid the visual perceptual discovery of the internal structure of the stimulus required to solve the problem. Or, a task could be designed for the purpose of the study. Such a test may sacrifice our knowledge of the test's reliability and validity.

Additionally, the short retest span may have masked research findings. Studies which have a reaction-time component have problems with order effects (Lombard & Riedel, 1978; McBrayer, 1992; Sattler, 1988).

Another possible limitation of this study needs to be noted. The setting in which a WAIS-III would be administered varied from this research setting. The WAIS-III is printed on paper with a matte finish. The research sample is on laser paper, which creates a gloss. This may have enhanced contrast in both the blue-only and the red-and-blue versions of the instrument. Laser paper is used to meet a demand in the market. It is made with a hard, smooth finish so that fibers do not come off and get into the machinery, thus minimizing maintenance costs.

Inversely, the findings could be accurate due to the methodological issues of design. The electronic medium states that once the color difference reaches a certain value it no longer influences human performance. It also states that when symbol size is small, color contrast enhances human performance (Carter & Carter, 1988). The symbols on the WAIS-R digit symbol may have been too large. When surround luminance is much greater than symbol luminances, then symbol brightness is reduced (Nagy & Sanchez, 1992; Carter & Carter, 1981). The result is to reduce the apparent color differences (Carter & Carter, 1981). Future studies could be designed which consider symbol size, surround luminance, saturation, lightness and hue with a greater systematic approach (see Appendix).

References

Arditi, A. (1997). Effective color contrast and partial sight. Brochure published by the Arlene R. Cordon Research Institute, The Lighthouse Inc. New York, NY.

Arditi, A. (1999). Effective color contrast: Designing for people with partial sight and color deficiencies. Brochure published by the Arlene R. Cordon Research Institute, The Lighthouse Inc. New York, NY.

Arditi, A. & Knoblauch, K. (1996). Effective color contrast and low vision. In B. Rosenthal and R. Cole (Eds.), Functional assessment of low vision (pp. 129-135). St. Louis: Mosby.

Arditi, A. & Knoblauch, K. (1994). Choosing effective display colors for the partially sighted. Society for Information Display International Symposium: 1994 Digest of Technical Papers, 25, 32-35.

Barret, P., Eysenck, H.G. & Lucking, S. (1986). Reaction time and intelligence: A replicated study. Intelligence, 10, 9-40.

Carter, E.C. & Carter, R.C. (1981) Color and conspicuousness. Journal of the Optical Society of America, 71 (6), 723-729.

Carter, R. (1982) Visual search with color. Journal of Experimental Psychology: Human Perception and Performance, 8 (1), 127-136.

Carter, R. (1989). Calculate (don't guess) the effect of symbol size on usefulness of color. Proceedings of the Human Factors Society, 33rd Annual Meeting. Washington, DC.

Carter, R.C. & Carter, E.C. (1988). Color coding for rapid location of small symbols, Color Research and Application, 226-234.

Chapparo, A., Stromeyer, C., Huang, E., Kronauer, R.E., et al. (1993). Color is what the eye sees best.

Cooper, B.A. (1985). A model of implementing color contrast in the environment of the elderly. American Journal of Occupational Therapy, 39, 253-258.

Eriksen, C.W. (1952). Location of objects in a visual display as a function of the number of dimensions on which the objects differ. Journal of Experiential Psychology, 44, 56-60.

Husband, T.H. & Hayden, D.C. (1996). Effects of the addition of color to assessment instruments. Journal of Psychoeducational Assessment, 14 (2), 147-151.

Jensen, A.R. (1987). Process difference and individual differences in some cognitive tasks. Intelligence, 11, 107-136.

Jones, G.I. (1976). The effect of color on the picture arrangement subtest of the WISC-R. Unpublished master's thesis. Brigham Young University, Salt Lake City, UT.

Knoblauch, K. (1993) A note on the theory of wavelength discrimination in tritanopia. Journal of the Optical Society of America, 10, 378-381.

Knoblauch, K. & Arditi, A. (1994). Choosing color contrasts in low vision: Practical recommendations. In A. C. Kooijman, P. L. Looijestijn, J. A. Guelling, & G. J. van der Wildt, (Eds.), Low Vision: Research and New Developments in Rehabilitation (pp. 199-203), Amsterdam: ISO Press, 199-203.

The Lighthouse Research Institute. (1995). Color contrast and partial sight.

The Lighthouse Research Institute. Investigations of color vision in low vision [On-line]. Available: http://www.lighthouse.org/1lh22r.html.

Lombard, T.J. and Riedel, R.G. (1978). An analysis of the factor structure of the WISC-R and the effect of color on the coding subtest. Psychology in the Schools, 15 (2), 176-179.

McBrayer, D.M.G. (1992). The effects of color versus black and white presentations on the picture arrangement and picture completion subtests of the WISC-III. Unpublished master's thesis, Marshall University Graduate College, South Charleston, WV.

Miles, S.M., Cook, D., Huertas, V., & Lyon, S. (1984). Productivity and comfort of the visually impaired worker as a function of a low vision aid usage and illumination/color contrast modifications. Technical Report. Rehabilitation Research & Training Center in Blindness & Low Vision, Mississippi State University.

Murch, G. M. (1984). Physiological principles for the effective use of color. IEEE. An earlier version was published in Tekniques 7 (4), Winter 1983.

Nagy, A.L. & Sanchez, R.R. (1992). Chromaticity and luminance as coding dimensions in visual search. Human Factors, 34 (5), 601-614.

Neubauer, A. (1990). Speed of information processing in the hick paradigm and response latencies in a psychometric intelligence test. Personality and Individual Differences, 11, 147-152.

Nissen, M. J., Pokorny, J., & Smith, V. C. (1979). Chromatic information processing. Journal of Experimental Psychology: Human Perception and Performance 5 (3), 406-419.

Pelaez, K. (1993). The effect of optometric vision therapy on WISC-III processing speed scores. Unpublished master's thesis, Marshall University Graduate College, South Charleston, WV.

Petry, D. (1989). Color versus black and white monochromatic display and the visual recall effect in children. Unpublished master's thesis, Marshall University Graduate College, South Charleston, WV.

Sattler, J. (1988). Assessment of children (3rd ed.). San Diego: Jerome M. Sattler.

Schweizer, K. (1998). The effect of two information processing skills on the speed ability relationship. Personality and Individual Differences, 14, 713-722.

Schweizer, K. (1998). Visual search, reaction time, and cognitive ability. Perceptual and Motor Skills, 86, 79-84.

Von Wright, J.M. (1970). On selection in visual immediate memory. Acta Psychologica, 33, 280-292.

Wechsler, D. (1981). Wechsler assessment of intelligence scales – revised: Manual. The Psychological Corporation, Harcourt Brace Jovanovich, Inc.

Williams, L.G. (1966). The effect of target specification on objects fixated during visual search. Perception and Psychophysics, 1, 315-318.

Appendix A

Review Of Literature

Pelaez' study (1993) examines the relationship of vision to performance on the WISC-III. The treatment variable was vision therapy. The dependent variable was the raw scores. Two subtests from the WISC-III were used to obtain processing speed index (PSI) scores. The subtests require the use of visual acuity and discrimination. The population studied was 25 elementary aged school children with vision deficiencies. A significant difference was found on pre-test and post-test scores, suggesting that improved visual acuity enhanced the test scores.

A recent study (Schweizer, 1998) hypothesizes that eye movements are related to cognitive ability. The appropriateness of eye movements was thought to show a relationship with the cognitive ability of adults with normal vision. Subjects of higher ability had greater appropriateness of eye movements than subjects of lower ability, although the correlation between appropriate eye movements and cognitive ability was small. The findings suggest that properties of visual search contribute to scores on measures of cognitive ability.

A variable which may influence eye movement is color contrast. Williams (1966) found color contrast to be related to relative fixation rate or glances. In Williams' search experiments, many different colors were included in relationship to glances on target – nontarget pairs. Williams concluded that it is possible to use the difference in color contrast as a predictor of glances. A mean search time of .5 seconds was equated to a difference of five hue units or three saturation units.

In a population with visual deficiencies, color contrast of lightness, hue, and saturation are manipulated to enhance human performance (Arditi & Knoblauch, 1994). Lightness is the amount of white or black shading in a color. Hue enables one to identify colors based on their wavelength. Saturation is the degree of color intensity. Thirty-five million people in the United States (1 in 20) have partial sight due to eye disease or congenital color deficits (Arditi, 1997).

Cooper (1985), in her article, offers a strategy to minimize information loss and decrease misinformation about the environment as result of enhancing visual search by color contrast. She proposes that color contrast will clarify key components of the environment. She bases her proposal on a literature review of 24 articles from 1968 to 1981. The literature examines three topics: environmental color, color cueing and coding, and factors influencing visual clarity. Her model is for the elderly population. However, Cooper postulates that it will be useful for any population that interacts with the environment. She addresses the limitations of her model by pointing out that there are no formal studies in the literature that support the perceptible attributes of color contributions to function at the time she developed her model. Yet, the model can be submitted to testing and the outcomes can be identified and quantified. She anticipates modification of her proposed model based on future findings.

Job performance and comfort of the visually impaired worker were considered in the following study (Miles, Cook, Huertas & Lyon, 1984). Two objectives of the study included defining indicators for the degree of variability among the identified optimum conditions between individuals, and the development of strategies for identifying optimum color contrasts for persons with severe visual impairments. The dependent variables were acuity and performance production rates. A single subject design was used in order to illuminate individual responses to the independent variables. Results indicated that acuity was significantly poorer for low contrast combinations. Performance measures indicated high color contrast combinations slightly superior to both low contrast combinations and black and white combinations. The study found optimum contrasts, based on the physical properties of hue, to be partially predictable, yet due to the different pathological conditions, somewhat individualistic as well.

An article published by the Vision Research Laboratory (Arditi & Knoblauch, 1996) makes practical recommendations for color contrast choices in the low vision population. The article's approach is based on qualitative, categorical properties of color and vision science. Five principles aide in selection of color choice that will maximize visibility for a population whose ability to distinguish hue has been diminished. The article addresses a need for revision of existing guidelines in the current standard of low vision literature. Examples of ineffective and effective color combinations are provided.

Two brochures have been produced by Lighthouse International, a worldwide leading resource on vision impairment and vision rehabilitation. The 1997 brochure teaches the reader about the three most important perceptual attributes of color vision. Vision scientists recognize hue, brightness and saturation as the most important attributes. People with normal color vision discriminate between colors on the basis of hue. As persons with color deficits have diminished ability to discern color based on hue, much attention is given to design guidelines with brightness and saturation. The pamphlet is in color. A color solid provides a graphic model of the three perceptual attributes. Hue varies around the solid. Lightness varies from top to bottom.

Saturation is the distance from the center. The 1999 brochure (Arditi and Knoblauch) differs from the 1997 format. The format implements in its design the guidelines discussed within the booklet.

Arditi and Knoblauch provide greater development of suggested guidelines for colored visual stimuli. A succinct article (Arditi & Knoblauch, 1994) was prepared for display designers. It points out how to optimize effective contrast while allowing for flexibility in use of color. This enables designs to be accessible to individuals with partial sight.

In additional article, "Effective Color Contrast and Low Vision" (Arditi & Knoblauch, 1996), they discuss how the three guidelines do not inhibit performance for people with normal color vision. They argue that their recommendations will increase visual accessibility, discriminability and/or legibility of environments, displays or colored print materials.

One reason to consider color in displays and colored print materials is that color may impact visual memory (Cooper, 1985; Petry, 1989). Petry studied the visual recall effect in children by comparing chromatic presentation of stimulus to achromatic presentation of stimulus. 50 grade school children viewed a test booklet of 40 words, one word per page. The words were in red, blue, yellow, or black ink. The findings indicated a color enhancement effect on visual recall. Petry concluded that color cueing facilitates the storage and recall of visual information. Stimulus materials and method of presentation need to be considered as sources of variance.

Color has been explored for its impact on reading performance. Reading performance, color contrast and luminance were studied (Knoblauch, Arditi, & Szlyk, 1989). Reading performance was measured for text defined by chromatic contrast with differing amounts of luminance present. When luminance contrasts were at the high value chromatic contrast did not influence reading performance. When luminance contrast was at the lower level, chromatic contrast sustained reading rates of nearly 300 words per minute.

The stimuli for this study were presented in the electronic medium. In the electronic medium, chromatic contrast is a variable that influences human performance on tasks with a visual search component (Carter, 1982; Carter & Carter, 1981; Carter & Carter, 1988; Nagy & Sanchez, 1992; Nissen, Pokorny, & Smith, 1979). Carter and Carter (1981) designed a study to explore how search time is related to the color difference between a target and background items. They studied 10 combinations of color contrast between targets and distracters. The outcome was human performance improved as the color differences between target and background objects increased.

Nagy and Sanchez (1990) measured response times as a function of color difference. The results demonstrated that up to a point, search time decreased in a regular way as the color difference increased. Search time was roughly constant once the color difference reached a certain level. The authors describe this phenomenon as the critical difference. Color difference enhances performance up to a point. Once that point has been reached, color difference no longer influences performance.

In another effects of color contrasts on visual search study, two types of searches were explored (Nagy & Sanchez, 1992). When color difference was small serial searches took place. A serial search is when the stimuli are searched in sequence. When color difference was large parallel searches occurred. A parallel search is a simultaneous search of stimuli. Nagy and

Sanchez explored human response as a function of color difference. With small color differences search time increased as the number of background distracters increased. With large color differences, as the number of distracters increased on the scene, human performance remained constant throughout three trials. With small color differences, the search time increased. The large color difference changed the search style from a sequenced search of stimuli to a simultaneous search of stimuli.

The study, "Chromatic Information Processing" (Nissen, Pokorny & Smith, 1979), investigates the chromatic processing channel only. In order to do so, the luminance is held constant in four experiments. In the first experiment response time was faster for shorter wavelengths than long. In the second experiment response time was faster with color presentations than achromatic. In experiments three and four, the brighter white surround decreased perceived brightness but did not effect response time.

Carter (1982) studied search speed for a target when the subjects knew the color of the target. Three factors influenced search speed. When the number of display items of the target's color increased from one to all items, search time increased linearly. The second factor which increased search time was when contrast between target and distracters was small. The third factor was placement of the target within or outside of a pattern. Average search time was longer when the target was within a pattern.

Achromatic pairs and chromatic pairs of color were found to influence visual search with small symbols. The achromatic pairs and chromatic pairs were part of the design in a study which explores the independent and interacting effects of symbol size and surround luminance on tasks with pairs of color stimuli. Statistical comparisons were performed with each color pair for the effects of symbol size, surround luminance, their interaction and the effects of larger color differences versus small color differences. Color difference includes the achromatic pairs (Carter & Carter, 1988).

Carter and Carter (1981) also demonstrate that two behavioral variables, relative fixation rate and search time, are related to color difference between target and background distracters. Two sets of data were also obtained for the relative fixation rate or glances. One set was studied with chromatic contrast and one with achromatic contrasts. The populations were college students with normal color vision. Twenty subjects were used for each set of data. Three formal equations for color contrast were compared. The results show that none of the equations are superior to the other. Color difference can be used for the construction of color codes to optimize visual search.

In human-computer interaction, color is useful to speed visual search and to organize categories of information. The article discusses the international CIELUV standard color difference equation adaptations and limitations in relationship to the electronic medium. The CIELUV equation was modified to account for symbol size. The size corrected CIELUV correction works. Even though the equation was designed for reflective surfaces (lightness) it was found to have the power to predict or explain performance in a context of changing symbol colors, different observers, changing display rastor brightness and widely varying symbol sizes (Carter, 1989). The author believes further research is necessary to address the difference between reflective images and brighter self luminous images. He provides guidelines for color contrast and symbol size as applied to display design on a computer monitor.

Murch, in a 1984 article, systematizes the comparison of how the eye creates color sensations to use of color on computer display monitors. He derives guidelines based on the needs of a users sensory system. Color occurs from the interaction of wavelengths of light with the nervous system. In the lens of the eye, wavelengths producing different color sensations are focused at different distances behind the lens. The lens does not transmit all wavelengths equally. The retina has light sensitive chemicals called photopigments. One type of photopigment is sensitive to short wavelengths. The other two photopigments respond to all wavelengths over the visual range. A color is signified by ratio of neural activities of the three photopigments. The ratio changes as wavelength of light changes. The author systematizes the use of color on display monitors based on the wavelength of a color and the manner in which the eye processes wavelengths.

As it has been demonstrated that the relationship of vision to performance on intelligence measures is currently being studied (Sattler, 1998; Schweizer, 1998; Wechsler, 1991) and that color contrast is a variable related to human performance in psychophysics, low vision and electronic medium, it gives rise to the need to explore color contrast in the design of the subtests of Wechsler measures of intelligence. The studies that do so compare achromatic to chromatic presentations of subtests. They do not address the perceptible attributes of color (hue, saturation and lightness) as sources of variance; nor do they address comparisons of contrast. The achromatic format is black, white and/or gray, which includes lightness variations only. A surface of zero saturation or hue appears white, black or gray. The chromatic format includes spectral colors. These colors have differing amounts of hue, saturation and lightness.

Jones (1976) studied the problem of achromatic and chromatic presentations of the WISC-R Picture Arrangement subtests. The chromatic presentation was the independent variable. The results, or raw and scaled scores were the dependent variable. The 60 students from third and fourth grades of two white middle-class elementary schools were randomly divided into two groups. One group of 30 received the achromatic version. The chromatic test was administered to the other group. The findings showed that the achromatic group scores were significantly higher on the raw and scaled scores and that there was a significant decrease in testing time. The limitations of the study include lack of differing populations, no attempt to analyze the effect of color on test taking attitudes and no analysis of different types of color, such as hues and lightness. The limitations denote possible sources of variance.

McBrayer (1992) notes a possible source of variance in changes in the stimulus cards of the WISC-R Picture Arrangement and picture completion subtests compared to WISC III. The WISC-R subtest stimulus cards were small, simple line art in achromatic format. The WISC III stimuli were revised by enlargement of the stimulus card and a chromatic format. Some of the objects and figures are in different shapes and sizes. In the Picture Arrangement subtest peripheral objects were added.

Lombard and Riedel (1976) when investigating the factor structure of the WISC-R, discovered the possibility of a color enhancement effect on the coding B subtest. They found a significant difference in raw and scaled scores when they compared the two color formats. The

76 subjects from 8 to 16 years had various learning problems. The authors believe further study is needed on a possible vision enhancement effect as it may lead to spurious low scores and a misdiagnosis of a deficit area in the Freedom from Distractibility factor.

Husband and Heyden (1966) attempted to determine a decisive evaluation of the effect of color enhancement on test performance of ability measures. A colored and non-colored version of the Absurdities subtest of the Stanford Binet, Fourth Edition and the Picture Completion subtest of the WISC-III were administered to 80 children. On the Absurdities subtest and the WISC-III Picture Completion subtests, color neither inhibited nor enhanced scores. The Picture Completion subtests were complicated by several interactions. The authors propose that changing subtests to color appears advantageous based on students' preference for colored stimuli.

Based on the above studies, it makes sense to explore the addition of color contrast to assessment instruments in a more systematic manner, comparing levels of contrast as opposed to the comparison of black and white to color stimuli. There may be a disadvantage to the less systematic comparison of color versus black and white. By not considering the levels of contrast presented by the color version and the black and white version, variables which lead to explanations of research findings could be overlooked.

Appendix

Variance Chart

Variables	Psychometric	Low Vision	Electronic
Hue		✓	✓
Saturation		✓	✓
Luminance		✓	✓
Chromatic	✓	✓	✓
Achromatic	✓	✓	✓
Chromatic Contrast		✓	✓
Achromatic Contrast		✓	✓
Raster Luminance		✓	✓
Symbol Size		✓	✓
Target			✓
Distracters			✓
Interaction		✓	✓
Findings			
Mixed Evidence	✓		
Partially Predictable *		✓	
Empirically Established			✓

* Partial predictability may be attributed to qualities of the population measured.

Acknowledgments

Special thanks to the thesis committee for their time and consideration. Each member made significant contributions. Appreciation to Dr. Del Lawhon for developing the cutting edge of my learning style. I am indebted to Dr. Stephen O'Keefe for his Socratic method. Both teaching styles contributed immensely to this study. Much gratitude to Dr. Teresa Eagle for agreeing to serve on the committee on short notice. Her knowledge of statistics and mentoring has contributed to the strength of this study. Gratitude is also is extended to Becky Sloan who in addition to supporting the professors, meets students needs with a cheerful, competent and efficient style. Thanks also to Sheri Koch, my rehabilitation counselor, for her perspective and support. Great appreciation is expressed to the Marshall University Graduate College library staff, especially Lois McCarthy.