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A Historical Review of Color Vision Standards for Air Traffic Control Specialists at Automated Flight Service Stations

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16. Abstract

This report chronicles several experiments the Civil Aerospace Medical Institute has conducted to assess the effects that advances in technology have had on automated flight service station air traffic control specialists color identification tasks and the ensuing revisions to the color vision standard and verification testing.

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INTRODUCTION

In conjunction with the celebration of 100 years of flight, this report provides a historical overview of the technological innovations within the automated flight service station (AFSS) facilities that subsequently affected the controllers' tasks and increased the demand on their color perception ability. Air traffic control specialists (ATCSs) at AFSS facilities brief pilots on weather conditions both before and during flights. The good news is that the ways in which weather information is obtained, coded, and conveyed have evolved from simply making *out-the-window* observations to having immediate access to worldwide, detailed weather information, color-coded and displayed on high-resolution monitors. As with many technological improvements, there are often unforeseen consequences that may adversely affect performance. Indeed, this was the case with the implementation of new weather displays. After all, there was no need for a color vision standard for early-day ATCSs who used teletyped textual information or who later used crude, 3-level monochromatic graphical depictions of the weather situation. However, as equipment changed, so did the demand on color discrimination ability and, consequently, the need to verify that ability.

As a result, the FAA now requires that all applicants for ATCS positions demonstrate their color discrimination ability because several ATC tasks involve critical, nonredundant, color-coded information. Furthermore, technological advancements now allow computers to produce 16 million colors. To take advantage of this new technology, many weather radar maps use a non-standardized, 16-level color code to depict various levels of reflectivity. Each level is related to the increasing probability of hazardous weather and is coded in shades of blue, green, yellow, red, purple, and white.

With the rapid proliferation of computer technology and the concomitant ability to utilize color in displays, it has become increasingly necessary to develop a color vision standard. Toward these ends, the Civil Aerospace Medical Institute has been involved in evaluating the changing color perception tasks of pilots and controllers for more than 30 years. The Civil Aerospace Medical Institute has also continually substantiated the need for a color vision standard. Furthermore, recommendations made to the Federal Air Surgeon derived from periodic re-evaluations of the standard necessitated revisions to the regulation to keep pace with changing technology. This report chronicles several experiments the Civil Aerospace Medical Institute has conducted to assess the effects that advances in technology have had on AFSS ATCS color-identification tasks and the ensuing revisions to both the color vision standard and verification testing.

HISTORICAL OVERVIEW

In the early 1920s when flight service station air traffic controllers first began providing weather information to pilots, there were no air-to-ground communications. According to *70 Years of Flight Service*, operators "made their own weather observations and forecasts, passing information to pilots during their ground stops" (Terrana, 1990, p. 29). Terrana (1991a, 1991b, 1992) chronicles the creation of the flight service stations—first known as Air Mail Radio Stations—to the AFSSs of today. The Weather Bureau, as it was called then, furnished textual weather reports that were transmitted to the flight service stations via teletype. Although only anecdotal information is available, it is believed that most operators converted the textual information to national, regional, or local hand-drawn maps fairly early. The maps used a color-coding system that depicted the various levels of weather intensities to better conceptualize weather patterns.

However, in the mid-1960s access to radar imagery became available. Using a monochromatic (one color) coding scheme, weather could be portrayed in shades of gray representing 3 levels of intensity. By the early 1980s, "color radar imagery could be accessed from National Weather Service radars (WSR-57 and WSR-74) and the Federal Aviation Administration (FAA) radars situated across the country" (WSI Corp., 2001). Six intensity levels displayed in color replaced the gray-coding scheme. The new digitized weather product was called the Radar Remote Weather Display System (RRWDS) and boasted the "most advanced state-of-the-art color weather radar display ever produced" with a "high resolution, non-interlace 60Hz raster scan of 512 x 512 pixels" (Talley Industries, undated product brochure, p.2). Not only could weather level colors be individually selected for viewing or masked (hidden), but users could select only the most intense weather levels to be shown, thus decluttering the display and emphasizing the most troublesome areas. Furthermore, specific colors could be set to blink, thus alerting the operator to the presence of that particular level.

At least three RRWDS design aspects added a level of redundancy to interpreting the color-coding. Features such as zoom, level select, and blinking enhanced color perception by increasing size or otherwise isolating specific coding and thereby protecting the performance of controllers with normal color vision over the range of viewing distances and consequent image size variation. Equally important, the redundant design features protected the performance of controllers with color vision defects. The weather intensity was depicted in 3 colors (green, yellow, and red), 2 intensities each, representing levels 1 through 6 (light, moderate, heavy, very heavy, intense, and extreme) as defined by the National Weather Service and the National Bureau of Standards. The system provided meteorologists at Air Route Traffic Control centers with detailed information on the location and severity of weather conditions nationwide by allowing the operator to *dial-up* any of several dedicated radar sites by entering its telephone number into a computer keypad.

During the 1980s, ATCSs experienced several technological changes made at flight service stations that revolutionized their tasks, including the invention of a monitor that allowed controllers to exchange their colored pencils for a color display of weather maps. Perhaps a carryover of the colors used in the paper-and-colored-pencils phase (or more likely the limitations of the display) and/or perhaps some remote connection to the cultural connotations attached to colors (such as green—go, yellow—caution, and red—danger) dictated the colors designated to represent each weather level. Regardless of the origin of the color-coding, by the mid-1980s color weather radar was being used to display weather information (see Figure 1).

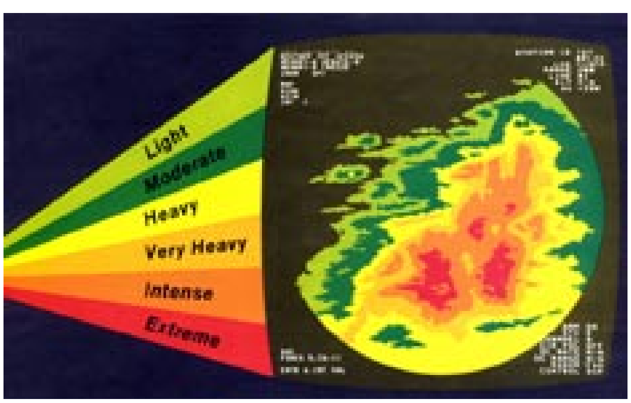

Figure 1. Radar Remote Weather Display System (RRWDS)

One of the first color codes in use illustrated bodies of water with the color blue and used two shades each of green, yellow, and red to represent 6 weather intensities on a black background. Basically, 16 colors were possible on the CGA (color graphics adapter) monitors with the red, green, and blue color guns. The 16 colors were hard-wired into CGA displays and consisted of full-intensity (light) and half-intensity (dark) versions of the primary colors and their combinations, plus white, black, and two shades of gray.

Additional technological changes allowed computers to produce 256 colors and, eventually, 16.7 million colors. Simultaneously, the resolution on the displays improved from 400 x 200 to 1280 x 1024 pixels. The improved resolution allowed weather maps to be presented in greater detail that more closely represented weather patterns. By the mid-1990s, color weather radar product suppliers expanded from 7- to 16-levels to represent a finer gradation of weather intensities (Table 1). A new program from the National Weather Service, called Next Generation Weather Radar (NEXRAD), was established with the goal of replacing the 128 aging WSR-57/74 radars in flight service stations across the country. The NEXRAD radars, called WSR-88D, were a new Doppler-type that allowed the user to see motion in atmospheric conditions. This enabled the user to view cold fronts, dry lines, and thunderstorm gust fronts as never before possible. A major advantage of NEXRAD was to provide early warning in cases of potentially severe weather. These technological advances and product improvements not only changed the job tasks, but also, presumably, the level of color vision ability required in air traffic control personnel. Because the older system, the RRWDS, had redundant cues available in addition to color that the new systems did not, the new systems required the user to rely more heavily on the color-coded information for interpretation. For those reasons, confirmation of one's ability to interpret the color-coded information became necessary, thus leading to a color vision standard and, subsequently, the need for a color weather radar work-sample test.

Color Vision Standards for All Controllers

Applicants for Federal Aviation Administration ATCS jobs in en route centers, terminal towers, and flight service stations were required to demonstrate their color vision discrimination ability as early as 1978, when Medical Guideline Letter Number B-5A-0002 was written. It required normal color vision for all ATCSs because a number of ATCS tasks involved critical, nonredundant, color-coded information. The following are ATCS tasks involving color-coded information identified by job analysis in the mid-1980s and used in subsequent research

Table 1

Comparison of 7-Level WSR-57 to the 16-Level WSR-88D Weather Intensities [a]

Refectivity Level[b]	Precipitation Intensity Levels: WSR-57		WSR-88D		Approximate Rainfall Rate
5-10			Level 1	Drizzle[d]	
10-15			Level 2	Light snow[d]	
15-20			Level 3	Light snow[d]	
20-25[c]	Level 1	Light	Level 4	Light	.02"/hour
25-30	Level 1	Light	Level 5	Light	.02"/hour
30-35	Level 2	Moderate	Level 6	Moderate	.09"/hour
35-40	Level 2	Moderate	Level 7	Moderate	.09"/hour
40-45	Level 3	Heavy	Level 8	Heavy	.48"/hour
45-50	Level 4	Very Heavy	Level 9	Very Heavy	2.5"/hour
50-55	Level 5	Intense	Level 10	Intense	5.7"/hour
55-60	Level 5	Intense	Level 11	Intense	5.7"/hour
60-65	Level 6	Extreme/Hail	Level 12	Extreme/Hail	12.9"/hour
65-70	Level 6	Extreme/Hail	Level 13	Extreme/Hail	12.9"/hour
70-75	Level 6	Extreme/Hail	Level 14	Extreme/Hail	12.9"/hour
>75	Level 6	Extreme/Hail	Level 15	Extreme/Hail	12.9"/hour

[a] original source of tabled information unknown
[b] measured in dBZ
[c] 18-25 dBZ for WSR-57
[d] precipitation may not be hitting ground

(Adams & Tague, 1985; Lahey, Veres, Kuyk, Clark, & Smith, 1984; Lahey, Veres, Kuyk, & Clark 1984; Mertens, 1990; Mertens, Milburn, & Collins, 1995, 1996, 2000; Pickrel & Convey, 1983):

1. Reading of red and black printing and also red and black (or blue) handwriting on flight progress strips used by ATCSs at en route facilities.
2. Scanning of color weather radar displays at en route centers and AFSS facilities. Blue, green, yellow, red, purple and white indicate different weather levels.
3. Identifying an aircraft's direction at night by tower controllers both while it is in the air and on the ground. Identification is based on red, green, and white navigation lights.
4. Identifying the color of the Aviation Signal Light indicator that gives a tower ATCS visual feedback concerning the signal light color (red, green, or white) that is used to direct an aircraft or ground vehicle when radio communication fails or is not available.
5. Identifying aircraft by the color of aircraft or its markings from within air traffic control towers in the daytime.
6. Reading a variety of color-coded charts at all types of facilities.
7. Selecting the appropriate colored indicator lights, keys, switches, and buttons at all types of facilities.

Not all of the above listed tasks are relevant to AFSS ATCSs. Furthermore, some of the tasks involve redundantly color-coded materials that would allow a person with color vision deficiencies to operate or interpret the meaning of the color-coding based on the availability of the redundancy. The built-in redundancies guard against misinterpretation of the simple color-coding. Tasks 5, 6, and 7 listed above have some built-in redundancy; and therefore, color-coding has a secondary importance. However, tasks 1 through 4 rely heavily or entirely upon color-coding to convey meaning to the user for interpretation. The primary color-related tasks include interpreting color coding on flight progress strips, aircraft navigation lights, and color weather radar images on a cathode ray tube (CRT). Most relevant to flight service is color weather radar.

Given the number of critical tasks that require ATCSs to decipher the meaning of the color-coded material, it is not surprising that "normal color vision" was a pre-employment job requirement. In this context, normal color vision refers to the way approximately 95+% of the population sees colors. Estimates vary, but about 8 to 10% of all males and about one-half of 1% of females see colors differently than the majority of people (Wyszechi & Stiles, 1982). Because a very high percentage of the population *match* colors in a similar way, they are said to have normal color vision. In contrast, those persons who see colors differently are labeled as color vision deficient. The incidence of color vision deficiency occurs across ethnic groups with the prevalence varying but with Caucasian males showing the largest ratio of red-green color vision deficients (Hunt, 1998; Pokorny, Smith, Verriest, & Pinckers, 1979). The initial, *normal color vision* pre-employment job requirement remained in effect until the Equal Employment Opportunity Commission regulation (29 C.F.R. Section 1613.705a) was written. It stated that an agency could not make use of any employment test that screens out qualified handicapped persons unless it is shown to be job-related for the position in question. Consequently, the first step was to substantiate the need for a color vision requirement. Justification for the screening test was based on its job-relevance, especially the non-redundant nature of color-coding in some ATCS tasks. However, making the connection between color vision screening test results and performance involving on-the-job tasks was harder to establish when the screening test was not composed of actual ATCS materials and/or tasks. At that time, the determination of normal color vision and one's capability of performing the color-related tasks was based on passing a pseudoisochromatic plate (PIP) test.

Need for Work-Sample Color Vision Tests

A court decision in 1980 determined that PIP tests were medical tests designed to measure genetically determined variations of color vision among individuals. Notably, the PIP tests do not predict the potential satisfactory performance of air traffic control duties related to color vision. This is an important point because the requirement that the applicant must have *normal* color vision should be interpreted to mean that the individual must be able to function normally in recognizing colors in the work environment. Consequently, the court found that ATCS applicants who did not pass the PIP tests should be given the opportunity to demonstrate their ability to recognize colors using work-sample materials.

In 1981, the Office of Personnel Management undertook an "examination of ATCS job requirements for color vision, asking nearly thirty ATCSs to list tasks that might require them to be able to distinguish and/or name colors" (Pickrel & Convey, 1983, pp. 4-5). From that list, "simulations of ATC tasks were created in three content areas: 1) aircraft colors for fuselage and lights, 2) color weather radar displays, and 3) navigational chart terrain elevations" (ibid., p. 5). The sub-tests consisted of color-identifications on ATCS task simulations and were assembled in a loose-leaf notebook requiring a paper-and-pencil answer sheet. The speeded test was called the Air Traffic Controllers Functional Color Perception Test (ATC-FCPT, Pickrel & Convey, 1983; Convey, 1985). Later, the ATC-FCPT was combined with the Dvorine Pseudo-Isochromatic Plates test and the Farnsworth D-15 test. Both of the latter tests used special disposition criteria, fully described in Mertens (1990). The resulting "Three-Test Battery" was then recommended by the FAA's Office of Aviation Medicine to test ATCS applicants who had failed their initial aeromedical color vision test. The scoring criteria for the Dvorine PIP (failure with 5 or more errors) and the special scoring procedure for the D-15 were based on recommendations of Lahey, Veres, Kuyk, Clark, and Smith (1984), who provided an in-depth "Job Analysis and Determination of Color Vision Requirements for Air Traffic Control Specialists" for the Office of Personnel Management.

In December 1985, the FAA's Medical Guideline Letter Number B-5a-0061 established a procedure for "Testing of ATCS Applicants Appealing Disqualification for Color Perception Deficiency." To be considered for employment as an ATCS, an applicant had to pass 2 of the 3 tests constituting the battery. That pass criterion was based on reports by Lahey, Kuyk, Veres, and Clark, (1984); Lahey, Veres, Kuyk, Clark, and Smith (1984); Pickrel and Convey (1983); and Convey (1985).

Re-Evaluation of the Work-Sample Test

Several years later, the Three-Test Battery was included in a study designed to determine the relationship between errors in performance of simulated ATCS color tasks and color vision deficiency "in order to evaluate the level of color vision ability required in ATCS personnel" (Mertens, 1990, p. 2). The Mertens study included all aeromedical color vision screening tests in use (in 1988) "by Aviation Medical Examiners (AMEs) for the initial medical examinations of ATCSs and pilots" (p. 4). The experiment included 9 PIP tests, 3 lantern tests, and 4 vision testers--all listed in the then current FAA Aviation Medical Examiner's Guide (1980). The study compared pass/fail performance on each of the FAA-accepted tests, the Three-Test Battery as a whole, and each of its component tests separately, to 4 simulated ATCS color-identification tasks: Flight Progress Strips, Color Weather Radar, Aircraft Lights, and Aviation Signal Lights. That study also used actual flight progress strips obtained from an en route center to serve as a criterion (work-sample) test to examine the predictive validity of the Three-Test Battery and other FAA-accepted tests. The study made a substantial contribution by analyzing performance on simulated ATCS tasks as a function of type and degree of color vision deficiency. Most importantly, findings from the study negated previous opinions about individual test performance and the predictive quality of each test—especially the Three-Test Battery. Although performance on the ATC-FCPT was poor, it was most likely because it was a cognitively difficult, timed test that was not strictly a color-perception test.

Based on results from Mertens' (1990) original study and a later replication study (Mertens & Milburn, 1992a), a new directive from the Federal Air Surgeon was written instructing regional flight surgeons to administer the Dvorine PIP, rather than the Three-Test Battery, to all individuals seeking initial employment with the FAA as ATCSs. In addition, the Medical Guideline letter described the course of action to be taken in the event an applicant failed the Dvorine PIP. Specifically, it stated that the applicant would be "notified of their opportunity to be re-evaluated" (MGLRM, 1995, MGL-87, p. 3).

Figure 2. Aviation Lights Test

The guidance stated that applicants who desired re-evaluation would be presented a repeat administration of the Dvorine PIP under standardized conditions. If no more than 2 errors were made, the person was passed and no further testing was required. The applicant thus qualified for all ATCS options. Otherwise, if the applicant failed the Dvorine PIP, the practical test that applied to a specific work option had to be passed for the applicant to be considered for that work option. The Aviation Lights Test (Figure 2) is the work-sample test for ATCSs wishing to work in the terminal option. The Flight Progress Strips Test (Figure 3) applies to the en route (or center) option and is composed of several flight progress strips lithographed onto the same green ledger paper used in the field. The notable difference is that in the Aviation Lights Test, the applicant identifies red, green, and white lights that meet the FAA (1988) and ICAO (1988) standards; whereas the Flight Progress Strips Test requires the identification of red and black printing.

Need for a Work-Sample Test for AFSS

At the time MGL-87 was issued, only the practical tests for the en route (center) and terminal options had been developed. Consequently, MGL-87 stated that an alternative color perception test for the flight service station option was under development at the Civil Aerospace Medical Institute. "Until another test is adopted, applicants for the flight service station option must successfully pass the Dvorine pseudoisochromatic plate test by making no more than two (2) errors under standardized conditions" (MGLRM, 1995, MGL-87, p. 3).

By 1993, in compliance with the above-mentioned directives from the Office of Personnel Management, the Equal Employment Opportunity Commission, and the Federal Air Surgeon, two practical (job-sample) tests had been

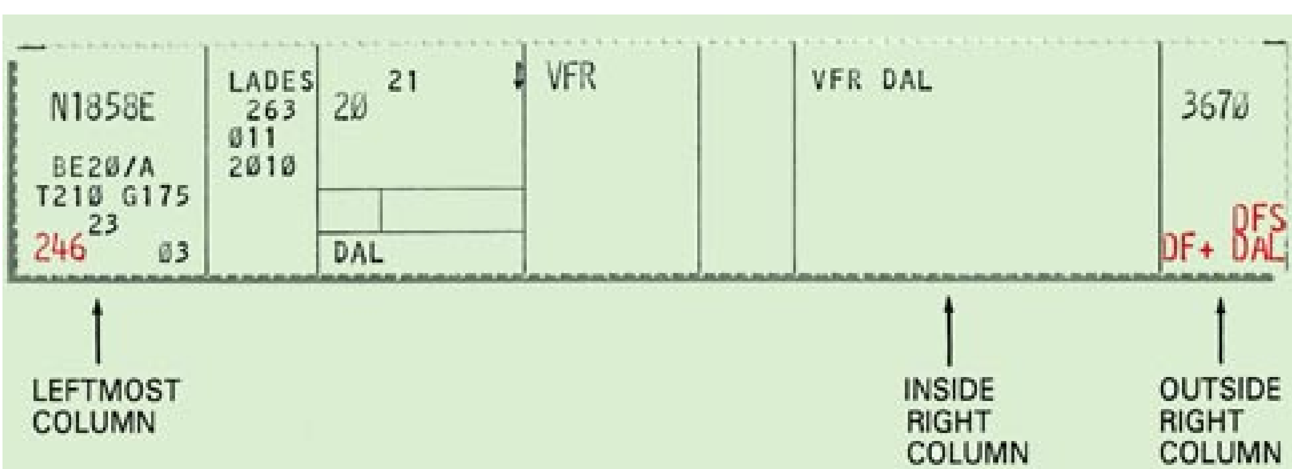

Figure 3. Flight Progress Strips Test

developed to allow ATCS applicants who failed their initial color vision screening the opportunity to demonstrate their color-vision abilities using simulated ATCS materials. Specifically, the color-related tasks described in Task 1 above were carefully reproduced in the Flight Progress Strips Test; and, similarly, Tasks 3 and 4 were simulated in the Aviation Lights Test (Mertens, 1990; Mertens & Milburn, 1992a; Mertens, Milburn, & Collins, 1996, 2000). Because Tasks 5, 6, and 7 have some inherent redundant coding available to the ATCSs to aid interpretation, only the task related to deciphering the color coding on a weather radar CRT had not been accomplished. Accordingly, Task 2 was addressed in an *initial* laboratory depiction of the AFSS color weather radar display that involved two concentric squares with the inner square representing the target color and the outer square representing various background or surround colors (Mertens, 1990). In that experiment, two target sizes were evaluated (0.1 and 0.5 degrees), but only 1 color palette measured at the McAlester, OK, AFSS containing 7 color-coded weather levels was duplicated in the laboratory. The participant's task was to identify the color of the inner square by color name and intensity such as light or dark--green, yellow, or red. All colors and intensities served as target and surround colors, and all combinations were presented. The targets were presented on 2-in squares on a black CRT screen. The small target size was used because discussions with AFSS ATCSs and meteorologists working at FAA facilities indicated that being able to identify the color of very small areas on a color weather radar display is important. In the laboratory, 7 of 31 participants with normal color vision made at least 1 color identification error on the 0.1-degree target (Mertens, 1990). However, the current weather displays used by ATCSs allow the user to "zoom" the weather image at any location on the display and thus enlarge the target to several times its original size. In defense of the small target size, the user must recognize a potentially hazardous area as such, to *know* to enlarge that area, leading to the conclusion that recognition of a small color-coded area is a prerequisite to prompt enlargement of the area.

Since that experiment, technological changes have allowed weather image providers to market improved products to AFSSs and, in turn, the technological advances have changed the demands on the user's color perception. One such product change occurred when weather image providers expanded the color coding from 7 levels to 16 in the NEXRAD system. Not only were new colors added to the original coding scheme, (e.g., blue, purple, and white), but several intensities of each color were possible. Although some composite radar displays using 7 levels are still in use, the 16-level weather product has gained wide acceptance because it more precisely depicts the weather situation. The National Weather Service generates weather information and/or radar images. From that information, a few companies produce color-graphic weather images that the FAA purchases. Each company is free to develop its own color palette for coding the weather levels. Additionally, some AFSSs locally produce some types of weather images that are unique to that particular facility.

Challenges and Design Issues of a CRT-Based Color Vision Test

One can quickly understand that creating a computerized color vision test that will re-create the AFSS ATCS's color discrimination tasks (relevant to Task 2) will present several challenges including accurately duplicating, on laboratory equipment, the colors that were measured at various AFSS field facilities. An initial survey revealed that each field facility uses a variety of brands and sizes of monitors. Because each CRT monitor has several adjustments available to the user such as brightness and contrast that act in conjunction with the individual limitations and capabilities of the monitor, color appearance differences exist between monitors. (This is similar to the differences apparent between television sets in a department store showroom.) Therefore, it is necessary to evaluate the effect on color perception as measured by test performance as a result of using different monitor brands, ages, sizes, and adjustments (with a specifically designated color card).

The second challenge will be producing a test with a clear, understandable task that captures the essence of the ATCS color-identification task that can be performed by applicants who have not received any ATCS training. The test has to be strictly a color vision test.

The third challenge of creating a computerized color vision test will be assuring that the colors used in the laboratory for test development and validation can be accurately reproduced on the CRTs at field testing sites. The CRTs must be calibrated on site just before testing with small tolerances specified for the chromaticities used in the test.

An important design issue will be selecting an appropriate target size for test trials of the color weather radar test. Previous work on the topic of target size revealed "the occurrence of some errors in normal trichromats… under adverse observation conditions in the flight strips and radar tasks…for identification of small targets on the order of 0.1 deg in size on radar displays" (Mertens, 1990, p. 8).

The next steps will involve selecting sets of color palettes for examination, creating an initial set of test trials, ensuring content validity, developing a scoring strategy, and establishing a pass/fail criterion. The final step will involve comparing performance on the Color Weather Radar Test to the Dvorine PIP as a function of anomaloscope diagnoses with its purpose being to identify individuals who fail the initial color vision screening test and who perform similarly to people with normal color vision on the work-sample test. Previous studies (Mertens, 1990; Mertens & Milburn, 1992a, 1992b; Mertens, Milburn, & Collins, 1998) reported high predictive validity values for the Dvorine PIP test (all reporting Kappas near .90) for simulated ATCS color-identification tasks. As with the practical color vision tests for the en route and terminal options, a few people were able to perform the work-sample tasks but were unable to pass the Dvorine PIP screening test. Mertens (1990) reported false-positive rates ranging between 7.1% and 35.8% for the Dvorine PIP test for prediction of performance on the 7-level color weather radar tests using small and large targets, respectively.

CONCLUSIONS

This paper has provided a historical review of the technological changes that have affected the color-identification tasks of the AFSS ATCSs and the subsequent changes to the color vision standards and testing materials. Furthermore, the paper introduces the challenges relevant to the development of a work-sample color vision test intended to allow AFSS ATCS applicants the opportunity to demonstrate their color vision ability while performing CRT-related color weather radar tasks. Specifically, the challenges and initial decisions include selection of an appropriate target size, size of monitors, brand of monitors, characteristics of the color palettes, number of colors used, and the presence or absence of a color legend.

Future Issues

Although the initial goal of using color on displays was to declutter, speed, and simplify the interpretation of textual information, now the number of codes possible are almost limitless by combining 16.7 million colors with many other display techniques (e.g., reverse video, flashing, brightness contrast, text size, and font). This is important because it has the potential to complicate the use of color displays by providing an overwhelming amount of information. So now, not only is color perception a vital issue but also the overall complexity of the color-coded display.

As additional uses of color are introduced by new advanced technologies entering the ATC terminal, automated flight service, and en route environments, clinical evaluations of the resulting changes to those ATCSs' knowledge, skills, and abilities must be conducted. Ultimately, as long as technology continues to change the controller's color identification job tasks, the work-sample testing materials used to verify the applicant's ability must also be dynamic to keep pace.

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