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New Genetic Technology May Help Pilots, Aviation Employees, and Color Vision Researchers

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Color vision research is not new for the Federal Aviation Administration (FAA); the Civil Aerospace Medical Institute has been conducting color vision research and publishing the results since 1967 (3). The FAA originally initiated color vision research because of the emerging use of color coding in the airport environment and the FAA has continued a line of color vision research because of the increasing use of color coding resulting from changing technology inside the cockpit, on air traffic control displays, and in the airport environment. Color can be used to convey meaning without supplemental signage such as the ubiquitous traffic signal that alerts drivers to proceed with caution via a yellow flashing light or to stop via a red flashing light. However, that meaning is only conveyed if the driver can distinguish between the yellow and the red colors. Approximately 8 to 10% of the male population (5) has a congenital color vision deficiency and, depending upon the type and severity of that deficiency, that task of interpreting the meaning of color coding may be difficult or impossible. Consequently, the FAA has long maintained a color vision standard for aero-medical screening to ensure that pilots and air traffic controllers can perform safety-related tasks without adverse consequences. Throughout the past few years, the FAA has explored a variety of color vision tests, searching for a valid screening test that has high sensitivity and specificity, meaning the ability to detect the presence or absence of the deficiency, respectively.

Basically, color vision tests can be categorized as diagnostic, screening, or occupational tests. Diagnostic tests are designed to specifically diagnose the type and degree of deficiency, the screening tests focus on differentiating between normal or deficient color vision, and the occupational tests seek to separate those capable versus incapable of certain tasks such as identifying colors of wires or lights (e.g., the Farnsworth Lantern test that was developed to assess the ability of potential Navy signalmen for identifying red, green, and white lights).

A few tests have been developed for the purpose of precisely diagnosing and classifying color vision; however, when color vision test scores are compared to performance on occupational tasks such as identifying or discriminating colors used in signal lights,

precision approach path indicator (PAPI) lights, colored navigation lights, color coded map reading tasks, color coded air traffic control displays, and cockpit displays, a specific cut-point on those selection tests has not been found that can fully separate those who can from those who cannot accurately perform the color-coded pilot or air traffic control tasks. Some tests, including new computerized instruments, have been designed to differentiate defects involving the long wavelength sensitive cones (protan-type), middle wavelength sensitive cones (deutan-type), and short wavelength sensitive cones (tritan-type). Congenital protan and deutan deficiencies are, collectively, extremely common, affecting 1 in 12 men and 1 in 230 women; however, recent evidence indicates that tritan defects are virtually never present at birth (e.g., congenital) and the inherited forms involve S cone photoreceptor degeneration that develops later in life with the exact onset depending upon the specific mutation (1, 4). Thus, the exact frequency of inherited tritan defects is uncertain; however, it is probably less than 1 in 500. In part, because the underlying pathophysiology has not been well understood, few tests have been available that are capable of detecting tritan deficiencies. In the past, those tests included the single Farnsworth F2 pseudoisochromatic plate (PIP), the Moreland anomaloscope, the Hardy, Rand, Rittler PIP test, and, most recently, the Oculus anomaloscope. Consequently, the occupational color vision tests used by most agencies only screen for the most common (protan and deutan) types of defects. The newly developed computerized color vision tests, including the Colour Assessment and Diagnostic Test, the Cambridge Colour Test, the Cone Contrast Test, and the Computerized Color Vision Test, are all designed to detect tritan defects. However, tritan weaknesses have been noted in several of the FAA ' s recent studies in much higher than the traditionally expected numbers and diagnostic agreement is low among those tests when tritan deficiencies are involved. In the past, the FAA and other regulatory organizations have not, or have rarely, required tritan color vision screening in their occupational screening because of the following three factors: the rarity of the congenital defect, the unknown number of individuals affected by acquired deficiencies, and the lack of effective, reliable, valid, and affordable equipment with which to diagnose the deficiency.

A New Technique

The capability of determining one's inherited color vision condition based on DNA (deoxyribonucleic acid) examination of the genes that encode the three types of cone photopigment responsible for normal color vision was recently announced (4). The test¹ was developed in collaboration with Professors Jay and Maureen Neitz of the Department of Ophthalmology at the University of Washington, who are considered pioneers in the cause and potential treatment² of color vision defects (4). The DNA test can provide a diagnosis of type and degree of inherited color vision defect. The DNA analysis test is performed in a single source, CLIA-approved³ laboratory and results are HIPAA-compliant⁴, are strictly confidential, and results are provided to physicians within 10–14 days. DNA samples are

¹The test is produced by Genevolve Vision Diagnostics, Inc., Albuquerque, NM, and is marketed under the Eyedox[®] brand name, available by prescription only from company-approved physicians. Genevolve Vision Diagnostics, Inc., is a life sciences company which researches, designs, and commercializes non-invasive molecular diagnostic assays and treatments for clinical applications to help people understand their color vision deficiency by receiving a proper color vision diagnosis and even improve their inherited color vision status.

²See <http://www.nature.com/news/2009/090916/full/news.2009.921.html>.

³CLIA: Clinical Laboratory Improvement Amendments; www.cms.gov/clia/.

typically collected and provided to the laboratory using non-invasive cheek swabs or saliva specimens, but any sample that possesses DNA can be examined to reach a comprehensive color vision diagnosis.

This service opens up a wide variety of possibilities. First of all, it will provide color vision researchers and test developers with a way to differentiate between types of inherited deficiencies (including protan, deutan, and tritan types) from those associated with trauma, disease, or exposure to substances that are toxic to the visual system. If an individual scores poorly on a diagnostic or screening test, but has no genetic markers for a color vision deficiency, one could conclude that the poor performance is most likely attributed to some other factor such as inattention, malingering, misunderstanding instructions, or a medical condition that has color vision deficiency as a symptom, or experiencing a side effect of a medication. For example, it could be a cerebral problem resulting from head trauma or a stroke, or an eye disease such as diabetic retinopathy, or exposure to a toxic chemical or a drug such as hydroxychloroquine that can have color vision problems as a side effect. This can be extremely valuable information because all other causes of color vision deficiencies besides inherited defects in the cone photopigments have other symptoms and color vision loss can be an early sign of an underlying condition. Besides differentiating the inherited forms of deficiencies from other causes for failure of a color vision screening test, another benefit of the DNA analysis is that it pinpoints the exact genetic mutation responsible for the color vision problem and it is unrivaled in its ability to determine type and severity. Knowing the type and severity of one's deficiency is important because of the greater safety consequences for protanopes (those missing the long wavelength cone) because they cannot differentiate some red lights from white lights based on color, but often use luminance to make a color decision, naming the brighter of two lights as white. Dichromats (either protan or deutan types) are missing one type of cone and are the most severe of the common color vision deficiencies. They only see 1% of the colors that an individual with normal color vision sees. At the other extreme, some anomalous trichromats can see as much as 50% of the color spectrum visible by those with normal color vision. Because color vision ability can vary widely among those within the color-deficient group — some seeing 1% while others see 50% — the within-group differences are at least as large as the between-groups differences found between color-deficients and color-normals.

Many aviation positions can be affected by color vision abnormalities and conventional testing may fail some that can adequately perform job functions and pass others that may pose a safety hazard. The FAA's research has found that some individuals with severe deficiencies have been able to make use of the redundant coding that is currently used in air traffic control displays with the same accuracy as individuals with normal color vision (2). So simply categorizing an individual as a color vision deficient without quantifying the type and degree of deficiency is insufficient, hence making screening tests that excel at differentiating between individuals with normal or deficient color vision inadequate for occupational testing, as is the case with typical PIP tests that denote pass/fail outcomes based on a normal/deficient color vision designation. Conversely, if a severity cut-point

⁴HIPAA: Health Insurance Portability and Accountability Act, U.S. Department of Health and Human Services; www.hhs.gov/ocr/hipaa/.

based on quantitative scores derived from genetic testing or precision computerized screening tests could be linked to occupational performance for a specific task, then knowledge of one's type and degree of deficiency might be a valuable pre-training, career choice tool that an individual could use prior to spending thousands of dollars in pursuit of his/her dream job only to discover in the final stages that they lack a key ability such as the ability to differentiate critical task colors.

A new line of research for the FAA involves administering precision, computerized screening tests in addition to measurement of DNA color vision genes of study volunteers to determine whether these quantitative measurement techniques will be able to shed sufficient light on the complexity of determining the appropriate level of color vision ability required to accomplish aviation color vision tasks or if the ability to discriminate redundant coding is still unaccountable. The purpose of that research is to determine if a precise connection can be made between the level of safe performance on occupational tasks and type and severity of one's color vision deficiency. If so, an individual may choose to have the DNA reflective of his/her cones analyzed prior to committing to a course of study that is known to involve color coding. The DNA analysis could be used to help an individual determine whether he or she has sufficient color vision ability to accomplish the color discrimination, color matching, or color naming tasks that are required for pilots or air traffic controllers. For example, pilots must be able to distinguish between the red and white lights of the PAPI system to facilitate landing, they must be able to match the map terrain to the elevation legend color, and they must recognize the colors of the signal light gun (red, green, and white lights that air traffic controllers use to communicate with pilots experiencing radio failure).

If DNA testing is no more definitive than currently available quantitatively scored color vision tests, we could conclude that there are separate abilities involved. In contrast, if a definitive link can be established between the DNA numeric score (reflective of the percentage of color perception that the examinee has compared to someone with normal color vision) and performance on actual or simulated aviation tasks such as identifying colored light-emitting diodes and incandescent lights or determining the elevation on a sectional map, then a prospective pilot could use that information to assist career decisions prior to spending thousands of dollars on flight school only to discover that the potential pilot does not possess sufficient color discrimination ability to safely fly aircraft equipped with sophisticated color-coded displays. If a link can be made in laboratory studies between acquired color vision deficiencies and performance on both precision diagnostic color vision tests and occupational tasks, then an additional value for the DNA analyses would be post-mortem DNA collection for forensic testing of crash victims, which may be helpful in unraveling accident causation because it would provide specific type and degree diagnosis of color vision deficient pilots to match to performance data gleaned from laboratory studies of subjects with similar diagnoses.

A very valuable outcome of the FAA's research will be determining the extent to which an acquired color vision deficiency, such as those caused by multiple sclerosis or as a side effect of various medications, hampers color identification or discrimination. With the distinction of acquired versus congenital defect now possible with DNA testing, researchers

will be able to link precision quantitative scores from diagnostic color vision tests to occupational tasks. This will be possible by denoting an “acquired color vision deficient group” after DNA testing has ruled out the existence of congenital deficiencies and group membership is further defined by those with quantitative scores on computerized color vision tests that fall outside the performance parameters for normal color vision. Hence, group scores on occupational color-coded tasks for those with acquired color vision deficiencies can be compared to those with normal color vision. It is important to evaluate the performance of those within this group on occupational tasks for at least two reasons. First, it is important because some acquired deficiencies can present as tritan-type deficiencies, a condition that is not currently a screening requirement for U.S. pilots and the prevalence within the population is unknown without the DNA distinction of any genetic markers. Also, it is important because it is possible that the following scenario, though it involves a very small percentage of pilots within all classes of certificates, could occur: a pilot with a congenital defect is given a statement of demonstrated ability (SODA) for color vision and, once issued, no further color vision screening is required during flight physicals because the severity of congenital defects does not worsen over time, with the exception of some changes that occur to most individuals as they age as a result of yellowing of the lens of the eye. Therefore, those pilots with a SODA that additionally “acquire” a color vision deficiency and those pilots with an acquired color vision deficiency of a tritan-type are both unscreened under the current FAA protocol. This current research project is expected to fill in some of the unknowns about the relationship between acquired color vision deficiencies and performance on occupational tasks, typical PIP tests, and computerized color vision screening tests, and whether a quantitative link can be established for those with congenital color vision deficiencies between occupational color requirements and severity of defect of a specific type.

Occupational Selection Decisions

It is important to emphasize that the FAA is bound by U.S. Equal Employment Opportunity, the Office of Personnel Management, and a federal court ruling⁵, in addition to the Rehabilitation Act of 1973 (that applies to federal employees) and the Americans with Disabilities Act of 1990 that requires that occupational tests must conform with the Uniform Guidelines for Employee Selection Testing for final determination of suitability for licensure/aeromedical certification (6). Furthermore, occupational selection decisions cannot be based on DNA because of the Genetic Information Nondiscrimination Act of 2008. Those restraints and ethical considerations prevent DNA data from being used at this time for purposes other than for research.

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⁵The requirement of the color standard was successfully challenged following the Americans with Disabilities Act of 1990. As a result, the FAA was required to develop an occupational test to determine if color vision deficient applicants had sufficient color vision to safely accomplish job duties, despite the published standard. This allowed qualification of candidates with less than normal color vision, provided they could discriminate information critical to air traffic control that is communicated using color.

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