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# ANALYSIS OF COLOR-SPECIFIC VISUAL PROCESSING SPEED DIFFERENCES IN DIVISION 1 COLLEGE FOOTBALL PLAYERS: A RETROSPECTIVE CHART ANALYSIS

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## ABSTRACT

**Introduction**

The University of Cincinnati has been doing NeuroVisual Training (NVT) as part of an injury prevention and performance enhancement program since 2010. We recently noticed that some athletes have substantial differences in visual reaction time based on color, specifically red versus green. We set out to assess if they may have had any color processing deficiencies.

**Methods**

We identified 4 out of 107 screened athletes with deficiencies in their ability to react to green compared to red. After identifying these color deficiencies, we developed a protocol to assess and manage the said deficiencies. The protocol included assessing for color blindness with the Ishihara plates, color Visual Evoked Potentials (cVEP), and color-based visual reaction times.

**Results**

None of the individuals had color blindness based on the Ishihara plates. There were significant differences in visual reaction times for red and green with red being significantly slower. cVEP mean red P100 latency was 115.5 ± 3.2 ms versus 104.4 ± 1.3 ms for green, and mean voltage was 7.30 ± 1.4 μV versus 9.20 ± 1.4 μV for green.

**Discussion**

NVT is becoming a mainstream means to improve performance and safety for athletes in competitive sports. It was interesting to note that high caliber athletes in a division 1 college football program were showing relatively slow visual reaction times. We were able to train them to a higher level of NVT proficiency once we included color-based tasks that best suited their ability to see and process quickly. People performing NVT on athletes may wish to be aware of and consider checking for color processing deficiencies such that one can train the athletes to the highest level possible.

**Keywords:** *color vision; dynavision; speed; speed of processing; sports; vision; vision processing*

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## INTRODUCTION

Color vision is X-linked in inheritance and is absent in as much as 8% of males and 0.5% of females of Northern European ancestry.[1] Color vision testing for children usually begins around the age of 5 or 6 years due to the motor and cognitive skills required to perform standard psychophysical tests. Visual evoked potentials (VEP) may be used as an objective tool to assess color processing and perception, and are generally accepted as a sensitive and objective test for assessing the integrity of the visual system.[2,3] Compared to those with normal color vision, those with color deficiencies have shown significant waveform changes in VEP, in both phase and amplitude of responses.[2] Other studies have shown that acquired color blindness can be severe without impacting VEP.[3] Interestingly, in at least one patient with significant loss of color sensation and capacity due to bilateral cortical lesions in the ventral occipitotemporal region, chromatic VEP (cVEP) waveforms remain unaffected in isolated color responses.[3] This may suggest that the site of the generator of the chromic pattern VEP lies proximal to the site at which color sensation arises and that normal VEPs to chromatic stimulation are not sufficient to deduce a normal sensation of color. Although the ventral occipitotemporal area is likely to have a selective role in color processing, it is not clear whether or not there are other cortical areas devoted solely to color processing or sensation.

The current case involves a series of four male football players. During the course of NeuroVisual Training (NVT) for Football, it was noticed that eye-hand reaction times were differing based on the color of the reaction stimulus. This was found while using the Dynavision D2 (D2) (Dynavision International LLC, Cincinnati, Ohio, USA) system.[4] We set out to determine if there was a processing or electrophysiological basis for this apparent difference in green versus red reaction times.

## METHODS

Inclusion criteria. This is a retrospective analysis of subjects who were identified based on differences in color performance parameters. Athletes identified with this deficiency have a protocol for characterizing the deficiency and optimizing performance enhancement. For this study, these differences were concerning red and green *A ("A star") scores using the dynavision D2.[4,5] Herein, we report on four males with a mean age of 21.8 ± 1.3 years.

The University of Cincinnati Institutional Review Board is the Institutional Review Board of record. This is a retrospective chart analysis of four University of Cincinnati athletes who were identified as having a color processing deficiency and went through our processing deficiency protocol as part of their injury prevention and NVT program.

All exams were performed by a single practitioner (B.T. J.). The players had the following tests: Retilab RetiPort Scan21 (Retilab) (Retilab LLC, Bristol, Wisconsin, USA) pVEP evaluation in white, red, and green; the D2 *A and reaction time evaluations in red and green; and Ishihara's Tests for Color Deficiency of Unlettered Persons.

### *Dynavision *A Method*

The Dynavision D2 *A test is provided by the manufacturer and is an established Dynavision protocol.[4,5] To perform the *A test, with both eyes open, the subject is told to stand as far from the board as possible, without leaning over, while holding the outermost lateral buttons. Next, the subject is informed that the buttons may light anywhere on the board and is instructed to hit the lights on the board as quickly as possible. Both hands may be used and the head and eyes may be moved. Score is reported as hits per minute (HPM).

### *Dynavision Reaction Test Method*

The central vision reaction time (CVRT) is tested with the Reaction Test on the Dynavision, which is another off-the-shelf, established Dynavision protocol.[4,5,6] This task requires the subject to use one hand at a time to press and hold one button, then when another button lights, the subject strikes the newly illuminated button.

### *CVEP Method*

The primary outcome measures are the N75 and P100 latencies and the signal amplitude ("voltage") as measured by the Retilab system. The pVEP is performed according to the International Society for

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**TABLE 1** Settings for pattern cVEP stimuli

| | |
|---|---|
| Visual angle of each check | 1° |
| Reversal frequency | 1.539 Hz |
| Number of reversals | 100 reversals |
| Mean luminance | 250 cd/m^2 |
| Pattern Contrast | 97% |
| Field size | 19 in (measured diagonally) |

Clinical Electrophysiology of Vision (ISCEV) standards.[7] The pattern reversal stimulus consists of an equal number of black and white checks arranged in a checkerboard pattern that change phase abruptly and repeatedly, according to the terms shown in Table 1. For chromatic visual evoked responses, the white checks are replaced with either fully red or fully green checks.

The electrodes were placed and the tests run using manufacturer's recommendations.

### *Color Vision Assessment Method*

Color vision testing was completed using Ishihara's Tests for Color Deficiency of Unlettered Persons. The manufacturer's recommendations were followed for measuring color vision.[8]

Optic nerve head, ganglion cell complex, and retina health assessment method.

As part of the routine pre-season baseline, and to rule out anatomic pathology, each football player completes scans of the *optic nerve head, ganglion cell complex, and overall retina*.[5,9] This test is performed on the Optovue IVUE Optical Coherence Tomography (OCT) machine (Optovue, Inc., Fremont, California, USA). The player is instructed to sit still with his head resting on a chin rest while the researcher completes six scans of each eye. Analysis of anatomical normality assisted by comparison against age-and-race-adjusted normative databases was included with the machine by the company.

### *Statistics*

Descriptive statistics (including mean and standard deviation), *t*-test, and ANOVA calculations were performed using Microsoft Excel 2016 Edition. Results are reported as mean ± standard deviation (SD).

## RESULTS

### *Dynavision Results*

Figure 1 shows the mean A Star scores for red and green, which were 51 ± 2.7 HPM for the red versus 93 ± 4.9 for the green lights. This difference was statistically significant (P = 0.0006).

The players' average Reaction Test reaction times, shown in Figure 2, were 0.44 ± 0.05s for red lights versus 0.32 ± 0.01 for green lights, which had a statistically significant difference of P = 0.021.

### *CVEP Results*

Mean red N75 latency was 85.1 ± 4.6 ms versus 79.9 ± 10.0 ms for green, mean red P100 latency was 115.5 ± 3.2 ms versus 104.4 ± 1.3 ms for green, and mean voltage was 7.30 ± 1.4 μV versus 9.20 ± 1.4 μV for green. Differences between red and green latencies for N75 were not statistically significant; however, both P100 and voltages show significant differences between red and green scores (P = 0.004113* and P = 0.01141*, respectively).

No overt color blindness was noted on the Ishihara plates. No abnormal thicknesses (Ganglion cell complex or Retinal nerve fiber layer) are seen on the OCT and Bixenman et al.[9]

**FIG. 1** Differences between hits per minute scores with red versus green lights on Dynavision D2 A* Test. Athletes were instructed to strike as many buttons as possible in 60 s; buttons light up continuously and randomly after one is depressed. Data are shown as mean hits per minute ± SD.

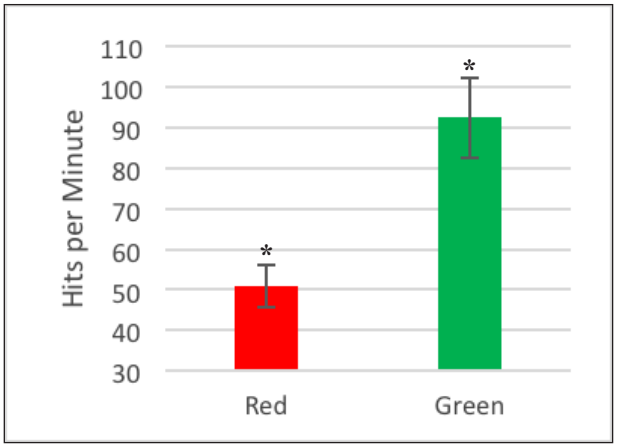


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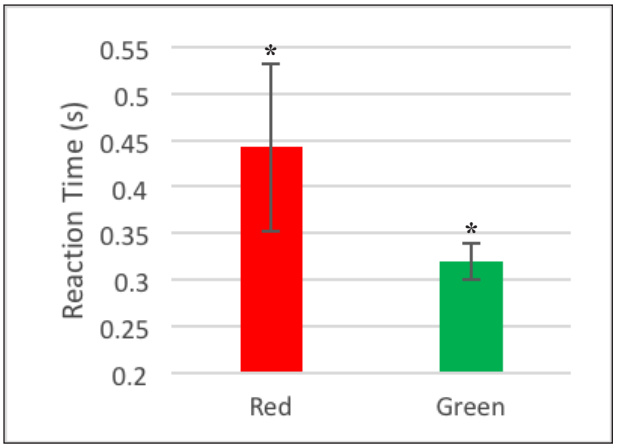
**FIG. 2** Differences between Reaction Test reaction times with red versus green lights on Dynavision D2. Athletes were instructed to press and hold a button until another button in their central field of view illuminates, and then as quickly and accurately as possible strike the newly lit button. Data are shown are mean reaction times in seconds ± SD.




## DISCUSSION

Our overarching goal in doing NVT for our athletes is to decrease injury risk.[5] We are also able to improve performance with our NVT program.[6] NVT is becoming more and more mainstream for sports performance enhancement.[10] We identified the four athletes with color-processing deficiencies because they were not performing some of the NVT tasks at a high level. In order to maximize the NVT training, we wanted the athletes to be proficient and enjoy their training. When we switched the athletes to more green tasks, their performance improved and they enjoyed NVT better. We do not completely eschew working with red, or their color deficiency. But, we allow them to thrive and succeed with the color tasks that they can do well.

With more and more sports medical as well as strength and conditioning coaches considering NVT for their athletes, we suggest they consider assessing color-processing deficiencies as a way to aid in progressing their athletes. For this study, we identified over 3% with a deficiency; it is likely that more will be found as the popularity of NVT increases. Below, we discuss the science and putative mechanisms where such a color processing deficiency may be occurring.

In this case series, we show data of division 1 college football players with significant differences between color differentiation and processing abilities for red versus green as assessed with the Dynavision light board. When examining their red scores for hand-eye coordination and reaction time on Dynavision, these players are slow compared to their peers.[5,6] On the football field, however, these players are not slow, as evidenced by three of the four players being starters and all earning significant playing time. On the field, as well as on Dynavision green tasks, they are on par with or even faster than their peers. Even their "slow" red scores are higher than our nonathlete norms.[5,6] Still, results from Dynavision show statistical differences with hand-eye coordination and reaction time between red and green. These differences are consistent with VEP voltage reductions and P100 latency shifts for red.

The deficiencies between red and green on these tasks do not appear to be related to any injuries or pathology as their OCTs were all normal (data not shown). In a nonscientific survey, we asked the players if the red versus green buttons appeared to have a similar brightness, to which uniformly all reported red to not be as bright as green. This is despite the manufacturer's claim of similar intensity for all color lights, which we confirmed via several smartphone apps designed and tested to measure lux.

Research has shown that children with established protan and deutan color vision anomalies can demonstrate loss of VEP amplitude and a phase consistent with the respective color significantly before college age.[2] Protan and deutan deficiencies are generally attributed to cone photoreceptors, and this suggests that cone deficiencies can contribute to color-specific VEP amplitude and phase shifts.[11,12] Therefore, the color-specific amplitude reductions and latency increases (phase shifts) observed in our players may be the result of them having fewer red cones than green. If so, it would be unlikely that the players are deficient in red cones and more so likely that they have either more green cones than normal or relatively/slightly more cones than red (due to their red scores being above

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general population norms and their lack of compliance with the symptoms). This may explain why, despite training, these players seem to have hit a ceiling or plateau with red, which is different (lower) from green and below expected abilities.[5,6,10]

If differences in cones caused these red and green discrepancies, then we might suspect the color-processing abilities of the two eyes to be inconsistent.[12,13] However, comparison of VEP latencies and amplitudes between left and right eyes shows no statistically significant differences in any of the four players.

Color vision loss and demyelinating disorders such as optic neuritis have been linked with retinal axonal loss visible in OCT imaging[9,14] and to increased error scores and N-wave latencies in VEP waveforms.[15–19] The players' baseline OCT scans, however, revealed that retina, optic nerve head, and ganglion cell complex anatomy are within normal, healthy limits (data not shown and Bixenmann et al.[9]). This suggests that the players' red/green differences are due to optic nerve or retinal dysfunction.

Moving deeper into the brain, we next examined the possibility of cortical defects. While cortical processing is essential for the perception of color, it may not be essential for physiological VEP response.[15,16] Because our players have significant differences in their VEP responses, upper-level visual cortex is not involved but rather simple processing or dysfunction in the lateral geniculate nucleus (LGN) may be responsible for observed differences between red and green. We cannot completely rule out upper-level involvement, though, because color perception involves multiple areas across a hierarchy of regions interacting with each other in a complex, recursive manner.[15] The neural generators of N75 and P100 are in the primary visual cortex, and the two components are physiologically distinct.[17,18,20,21] Furthermore, L/M cone signal processing already present in the retina and LGN is also observed at the visual cortex and a lack of either photoreceptor types led to a dominance of the ON pathways of the remaining photoreceptor type.[7,15] This inverse relationship may explain why our players have diminished perception of and speed with red, which is significantly different from green. More research is needed to determine if the red/green differences involve the LGN or primary visual cortex with this apparent processing deficiency.

It is worth reiterating that while Dynavision data are statistically significant, it was inclusion criteria for the study and that mean functional parameters assessed by Dynavision for both red and green were within general population norms. We conclude that the apparent processing speeds for eye–hand-based activities are overall NOT due to color-blindness-related deficiencies, but that some color-processing deficiencies can negatively impact the speed of visual processing of the color red in these subjects. This is novel because other studies, concerning neuro-visual training, have not considered the links between color vision deficiencies and differences in speed with color-specific tasks. We did not and will not do genetic testing on the players involved as this is a retrospective analysis and our protocol does not include genetic testing. The small n and lack of control are due to our only reporting these findings as a retrospective case series. A possible source of error exists in our methods for multicolor VEP testing as tests were performed sequentially without breaks. In future studies, we would like to examine how blue light and white light are perceived and processed by similarly testing individuals, and then compare those results to these where possible. We would also like to do multicolor ERG testing to further support proper retinal function, followed by multifocal VEP with red and green stimuli to aid in localizing the source of these processing differences.

Some limitations to this study are that it is a retrospective chart analysis of subjects who entered our color-processing deficiency protocol. As such there is no control group and no intervention. We only conclude that there are color-processing deficiencies that may impact some parameters of NVT.

In conclusion, we suggest that speed of color processing may contribute to apparent deficiencies in the ability of some individuals to see and react to certain colors. In this case series, we examined red deficiency compared to green. For NVT to improve athletes' safety and performance, it may be important to look for and address such deficiencies as a means to maximize performance when doing NVT.

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## DISCLOSURES

The authors declare that there are no conflicts of interest related to this article.

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