# Association of Functional Color Field Changes with Imbalance, Spatial Misjudgment, and Nausea in the Treatment of Post-Concussion Syndrome Patients

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Background:
The purpose of this retrospective review is to investigate the relationship of functional color fields with imbalance, spatial misjudgment, and nausea in post-concussion syndrome. Secondarily, a therapeutic goal for color field improvement in this patient population is proposed.

Methods:
The participants are 60 consecutive post-concussion syndrome patients presenting to this author's clinic. The design is a retrospective review of subjective and objective measures one week before and 38 days after initiation of neuro-optometric rehabilitation. The main measures reviewed are functional color fields, the Berg Balance Scale, survey responses in imbalance, spatial misjudgment, and nausea, and visual evoked potential amplitudes.

Results:
Patients who obtained a 20% or greater improvement in functional color fields exhibited on average a 63%, 98%, and 71% greater improvement in symptoms of imbalance, spatial misjudgment, and nausea, respectively, compared to patients whose functional color fields improved less than 20%. Clinical testing using the Berg Balance Scale revealed a 380% greater improvement in balance performance compared to patients whose functional color fields improved less than 20%. Visual evoked potential amplitudes demonstrated an inverse relationship with symptom improvement in imbalance, spatial judgment, and nausea.

Conclusion:
A direct correlation is revealed between functional color field improvement and recovery from imbalance, spatial misjudgment, and associated nausea when patients receive neuro-optometric rehabilitation. A hypothesis resulting from these observations is that visual system pathways involved in balance and spatial awareness are therapeutically affected by optometric intervention and functional color fields can be utilized as a clinical marker to gauge change. Additionally, a therapeutic goal of 20% or more in blue color field improvement could be considered when optometrists treat post-concussion syndrome patients presenting with symptoms of imbalance, spatial misjudgment, and associated nausea. Finally, the inverse relationship of visual evoked potential low contrast amplitude findings may provide speculation that therapy directed toward these symptoms acts to a greater extent on the auxiliary and secondary visual pathways that integrate with other balance mechanisms than it does on the primary visual pathway.

Keywords: post-concussion syndrome, multi-sensory integration, spatial awareness/misjudgment, Berg Balance Scale, optometric phototherapy, functional color fields, visual evoked potential

## Introduction/Background

Balance difficulties are present in approximately 50% of patients with post-concussion syndrome.[1] **Post-concussion syndrome (PCS)** is a set of symptoms that may continue for weeks, months, or more than a year after a concussion.[2,3] Patients exhibit balance challenges in numerous ways. This includes: disequilibrium, not feeling grounded, stumbling, difficulty with turning, clumsiness or difficulty coordinating movements, looking downward to confirm the location of the ground, and holding onto something when standing. As a result, patients are at risk for falls and resultant further injury.

The classical medical view of balance difficulties involves association with vestibular dysfunction. And a commonly followed standard of care for imbalance by medical physicians is a referral to a physical therapist specializing in vestibular therapy. Although this protocol often results in a successful outcome, it is not unusual for this single sensorimotor therapy approach to fail. Balance is dependent on the integration of multiple sensory inputs including visual, vestibular, and somatosensory systems.[4] These three systems form a "tripod" which is used in nearly all activities of daily living to correct and provide balance and instinctive awareness of one's location in the environment.

Brain injury can cause damage to an isolated system compromising the integrity of the tripod due to sensory conflict. However, brain injury more often results in damage to the integrative networking of these multiple sensory signals, otherwise known as multi-sensory integration. **Multi-sensory integration** describes a process by which an intact, well-developed brain can integrate information from multiple senses and modulate these inputs for optimal awareness and reactivity to the environment.

When vision is a causative component, the resultant imbalance is often accompanied by difficulties with spatial awareness. **Spatial awareness** is the ability to be accurately aware of oneself in space. It is an organized knowledge of objects in relation to oneself in that given space. Spatial awareness also involves understanding the relationship of these objects when there is a change of position.[5] Deficits in spatial awareness lead to **spatial misjudgments**. For example, a patient may have difficulty navigating crowded stores, doorways, curbs and stairs. They may also miss-reach and inaccurately grasp for objects.

A basic explanation of the underlying neural mechanisms responsible for balance and spatial awareness is of value for this article. It is commonly thought that there are two primary pathways of visual input, the parvocellular pathway and the magnocellular pathway. Dr. Deborah Zelinsky explains that the magnocellular visual pathway consists of both sub-cortical processing (superior colliculus) for the reflexive "Where am I", and cortical processing (parietal lobe) for "Where is it?[6] There is also extensive interplay amongst these networks that is synchronized in a healthy brain. For example, the superior colliculus receives both retinal and cortical input and utilizes this information to influence brainstem structures and the spinal cord for motor output involved in balance and gait.[7] Additionally, the parietal lobe mediates several aspects of spatial awareness such as navigating and reaching into the environment. This is accomplished via the posterior parietal cortex (PPC) containing neurons responsible for changes from retinal-centered to body-centered coordinates.[8]

Nausea is often present and associated with balance difficulties when the vestibular system is a causative factor. This is because the vestibular system is highly innervated with the gastrointestinal system.[9] Therefore when there is vestibular dysfunction, or the vestibular system is being affected by inefficient visual inputs during visual-vestibular integration, the gastrointestinal system will sometimes display the effects.

Optometry has an opportunity and a responsibility to help rehabilitate patients who have imbalance and spatial misjudgment via the visual system. Optometric tools such as lenses, prisms, filters, and tints can be used to stimulate the retina and alter the optic flow to the brain.[6] These methods of changing visual inputs thereby affect brain function.

**Optometric phototherapy** is the application of filtered light (within the visible spectrum) through the pupil to the retinal blood supply and to retinal photoreceptors. It is a method of neuromodulation using phototransduction - photons of light activating a graded change in membrane potential and a corresponding change in the rate of transmitter release onto postsynaptic neurons.[10] Optometric phototherapy is becoming a more frequently utilized technique during neuro-optometric rehabilitation.

During clinical use of optometric phototherapy, the effect that the prescribed light has on brain function is clinically gauged with functional color fields. **Functional color fields** is a near point visual field test used as an indicator of visual performance and therefore of brain function.

## Methods

The participants were 60 consecutive PCS patients presenting to the authors clinic during the period of February 8, 2016 to July 12, 2017. No patients were excluded. Each patient was de-identified via meeting safe harbor requirements under section 164.514(a) of the HIPAA Privacy Rule.[11] Forty-nine of the 60 patients presented with the symptom of imbalance, 49 with spatial misjudgment, and 26 with nausea. Patient ages ranged from 14 to 73 with a median age of 36.5. The time between most recent concussion and initiation of treatment ranged from 24 to 1468 days with a median time of 734 days. Twenty-six were men and 34 were women. The number of previous concussions ranged from 0 to 14. No patients had received any prior optometric vision rehabilitation.

The neuro-optometric rehabilitation protocol utilized targeted multi-sensory integration via simultaneous application of optometric phototherapy, vestibular stimulation, auditory stimulation, and gradually applied versional and vergence oculomotor therapy. It consisted of 12 consecutive days of in-office visits each lasting 75 minutes followed by 18 days of home therapy. During the 12 days of in-office therapy, each patient received colored light therapy progressing through magenta, ruby, yellow-green, yellow-blue, violet, and magenta again. The order, exposure time, and combination of filters was determined based on integration of principles taught by the College of Syntonic Optometry and the Sensory Learning Institute. The subsequent 18 days of home light therapy was magenta. The vestibular stimulation and the auditory training were techniques and proprietary programs of the Sensory Learning Program. The oculomotor therapy was minimally applied initially consisting of five to ten minutes of monocular (progressing to binocular) saccadic and pursuit activities. Convergence therapy was gradually introduced as tolerated without aggravating patient symptoms. These activities increased in difficulty during the in-office phase of treatment. Balance activities were gradually added to further rehabilitate integration of sensory motor pathways.

The clinical measures that were reviewed included functional color fields, a balance assessment test, visual evoked potential amplitudes, and symptom survey responses by the patient in the areas of imbalance, spatial awareness, and nausea. These measures occurred one week prior to the initiation of the therapy and 38 days post initiation of the therapy.

| | SCAT3 Reported balance improvement | Berg Balance Scale improvement | SCAT3 reported nausea improvement | ABI Survey reported spatial misjudgment improvement |
|---|---|---|---|---|
| Color fields increase OU of >20% | 57.4% (N=14) | 31.7% (N=14) | 96.3% (N=9) | 24.4% (N=14) |
| Color fields increase OU of <20% | 35.2% (N = 22) | 6.6% (N = 23) | 56.3% (N = 12) | 12.3% (N = 21) |
| Improvement differential between ">20%" and "<20%" | 63.1% | 380.3% | 71.1% | 98.4% |

*Table 1*

The functional color fields (green, red, and blue) were measured monocularly utilizing the FCF Tester computerized program. The parameters for each patient were the following: 1.6 mm diameter target size; target presentation speed of 36mm/second; target brightness setting for each color was 176 (no unit); random order of presentation of the three colors; each target presentation began at 30 degrees from center; twelve meridians were tested at 30-degree intervals; central fixation target was a single digit that randomly changed and flashed at a frequency of once per 1500ms.

The balance assessment was obtained using the **Berg Balance Scale (BBS)**. This is a widely used clinical test of a person's static and dynamic balance abilities. The BBS is generally considered to be the gold standard of functional balance tests.[12] The test comprises a set of 14 simple balance related tasks, ranging from standing up from a sitting position, to standing on one foot. The degree of success in achieving each task is given a score of zero (unable) to four (independent), and the final measure is the sum of all the scores.[13]

| Color field increase: | | SCAT3 Balance improvement >20% | SCAT3 Balance improvement < 20% |
|---|---|---|---|
| Green | OD | 51.5% | 38.6% |
| | OS | 30.9% | 47.8% |
| Red | OD | 56.4% | 50.2% |
| | OS | 53.3% | 39.3% |
| Blue | OD | 63.8% | 31.5% |
| | OS | 65.5% | 26.5% |

*Table 2*

| Color field increase: | | Spatial Misjudgment Improvement > 20% | Spatial Misjudgment Improvement < 20% |
|---|---|---|---|
| Green | OD | 35.1% | 22.6% |
| | OS | 35.5% | 28.7 |
| Red | OD | 42.4% | 32.6% |
| | OS | 42.4% | 28.7% |
| Blue | OD | 53.2% | 8.6% |
| | OS | 40.7% | -15.1% |

*Table 3*

Visual evoked potential amplitude measurements were obtained monocularly using the Diopsys Nova 32 special frequency configuration with multi-contrast stimulus pattern at both low contrast and high contrast to test the integrity of the magnocellular and parvocellular pathways, respectively. The **visual evoked potential** (VEP) objectively measures functional responses of the primary visual pathway including the retina, optic nerve, optic radiations, and visual cortex. Electrical signals are measured from the electrophysiological activity at the visual cortex. VEP recordings have been used for a variety of applications that involve neuro-visual disorders including traumatic brain injury.[14] To be included in data, patient responses were required to have a minimum of 80% reliability factor. See "N" values in Table 7.

The symptom survey used for patient symptom reporting of imbalance and nausea was from The Sports Concussion Assessment Tool, 3rd edition (SCAT3). This is a widely used concussion survey that measures a global range of self-reported symptoms. The patient rates 22 symptoms on a scale from zero to six.[15] The tool utilized for subjective tracking of the symptom of spatial misjudgment was an acquired brain injury symptom survey this author developed. The patient rates 15 symptoms on a scale from zero to four.

**Results**

An overview of color field changes comparing pre and post therapy revealed a positive correlation between color field size increase and improved

| Color field increase: | | SCAT3 Nausea improvement | |
|---|---|---|---|
| | | > 20% | < 20% |
| Green | OD | 76.7% | 51.9% |
| | OS | 69.4% | 51.2% |
| Red | OD | 83.3% | 37.5% |
| | OS | 70.8% | 47.5% |
| Blue | OD | 86.7% | 46.4% |
| | OS | 83.3% | 41.8% |

*Table 4*

| Color field increase: | | Berg Balance Scale Improvement | |
|---|---|---|---|
| | | > 20% | < 20% |
| Green | OD | 28.2% | 9.1% |
| | OS | 26.2% | 5.4% |
| Red | OD | 35.0% | 8.4% |
| | OS | 35.5% | 6.9% |
| Blue | OD | 29.8% | 8.9% |
| | OS | 29.6% | 8.0% |

*Table 5*

balance (as evidenced in the SCAT3 symptom survey and the BBS). This propelled a review to look at whether a certain threshold exists in color field improvement relative to balance improvements. After examining changes in balance measures at color field improvements of 10%, 20%, 40%, 60%, and 80% it became evident that 20% was where a significant increase in improvement in balance occurred. The patients who obtained 40% or above increase in color fields did not report a greater improvement in balance compared to the 20% group. Further review of the 20% group revealed a parallel improvement in spatial misjudgment and nausea with the improvements in balance measures. See table 1 for a summary of these findings.

| | SCAT3 Reported balance improvement | Berg Balance Scale improvement | SCAT3 reported nausea improvement | ABI Survey reported spatial awareness improvement |
|---|---|---|---|---|
| Blue nasal field increase OU of >20% | 66.7% (N=11) | 32.9% (N=12) | 85.7% (N=7) | 50.0% (N=12) |
| Blue temporal field increase OU of >20% | 59.4% (N=12) | 33.6% (N=12) | 81.5% (N=9) | 53.5% (N=13) |
| Both blue nasal and temporal field increase OU of >20% | 82.7% (N=5) | 43.2% (N=7) | 100% (N=2) | 59.5% (N=7) |
| Neither blue nasal *nor* temporal field increased > 20% | 10.8% (N=8) | 8.9% (N=9) | 52.5% (N=4) | 9.25% (N=9) |

*Table 6*

Regarding balance, the patient group (n=14) who exhibited a greater than 20% increase in the average of all three color fields in both eyes reported an average balance improvement of 57.4%. The patient group (n=22) who exhibited a lesser than 20% increase in all three color fields in both eyes reported an average balance improvement of 35.2%. This represents a 63.1% difference. Substantial differences between the ">20%" group and the "<20%" group also existed in Berg Balance Scale, spatial awareness, and nausea of 380.3%, 98.4%, and 71.1%, respectively.

A specific review of each color field in isolation revealed that the blue fields are the most strongly correlated with improvements in balance and spatial misjudgment symptoms. See tables 2 and 3. Nausea symptoms and Berg Balance Scale improvements are displayed in Table 4 and 5, respectively.

A comparison of temporal field versus nasal field improvement showed no difference in symptom improvement. However, the patient group that gained >20% in both temporal and nasal fields benefited far more than their <20% counterpart group. See Table 6.

VEP low contrast amplitude data exhibited an inverse relationship with imbalance and spatial misjudgment symptom changes. The groups that demonstrated no improvements in VEP low contrast amplitudes reported greater improvements in balance and spatial misjudgment than the groups that demonstrated improvements in VEP low contrast amplitudes. See Table 7. VEP high contrast amplitudes exhibited no consistent correlation.

**Discussion**

The results of this retrospective study demonstrate the usefulness of functional color field testing as a clinical measure when monitoring the therapeutic effects on imbalance, spatial misjudgment, and associated nausea during neuro-optometric rehabilitation of PCS patients.

Rehabilitation specialists in various professions rely on established standardized goals when programming a patient's therapy for both clinical guidance and insurance documentation purposes. This study suggests a minimum of 20% increase in the blue color fields as a standard goal by optometric practitioners when providing vision rehabilitation for PCS.

Retinal anatomy supports that the blue fields are of primary interest when monitoring balance and visuospatial function. Blue light sensitive cones have a much greater existence in the peripheral retina than red and green cones. Additionally, origination of the magnocellular vision pathway (the pathway that provides the visual influences on balance and spatial awareness) in the retina is represented by parasol ganglion cells. These cells, like the blue sensitive cones, dominate the peripheral retinal geography when compared to the midget ganglion cells (parvocellular visual pathway retinal cells).[16] It can thus be construed that expansion of the blue color field would parallel enhanced magnocellular processing ultimately affecting performance in balance and spatial judgment.

This author proposes that percent change in field size be the specific method of quantifying the functional color field changes versus a specific field size. This allows the treatment goal to be universal and independent of the existing variance in equipment, methods, and parameters used during the measuring of color fields amongst practitioners.

VEP low contrast amplitudes demonstrated an inverse relationship with degree of improvement in balance and spatial misjudgment. This author speculates that the treatment acted upon secondary and auxiliary visual pathways (not represented by VEP testing) versus the VEP-based retina-geniculate-visual cortex pathway. And since the auxiliary and secondary pathways have more integration with balance related neural mechanisms, it is possible to have greater balance improvement inversely and/or independent from the VEP amplitude changes.

## Conclusion

This retrospective study provides evidence-based support for what the late Dr. Charlie Butts once stated, "functional color fields are a very sensitive method of monitoring the progression of a patient's vision therapy program, especially if optometric phototherapy is involved". This study involved a treatment protocol that utilized optometric phototherapy and oculomotor therapy to modulate the optic flow throughout the visual pathways of the brain while stimulating other mechanisms involved in balance. This multisensory approach demonstrated that imbalance and spatial misjudgment recovery after concussion is more efficacious if functional color fields expand beyond 20%, thus providing a mechanism to monitor progress.

| | OD | | | OS | |
|---|---|---|---|---|---|
| | VEP Lc Amp Improved | VEP Lc Amp Not Improved | | VEP Lc Amp Improved | VEP Lc Amp Not Improved |
| Balance Improvement | 27.5% (N=12) | 50% (N=11) | | 32.7% (N=10) | 54.5% (N=11) |
| Spatial Misjudgment Improvement | 15.9% (N=11) | 31.1% (N=15) | | 26.7% (N=10) | 31.3% (N=16) |

***Table 7***

Optometric clinicians should consider setting a therapy goal of a 20% or greater increase in blue color fields when establishing the plan of care for PCS patients that present with imbalance and/or spatial misjudgments. Of course, functional color fields should not be utilized in isolation but rather as an additional clinical marker to the patient's overall vision rehabilitation program. Further study is needed to investigate the application of this clinical marker in other patient population types. VEP did not demonstrate potential usefulness as a clinical marker for this patient population.

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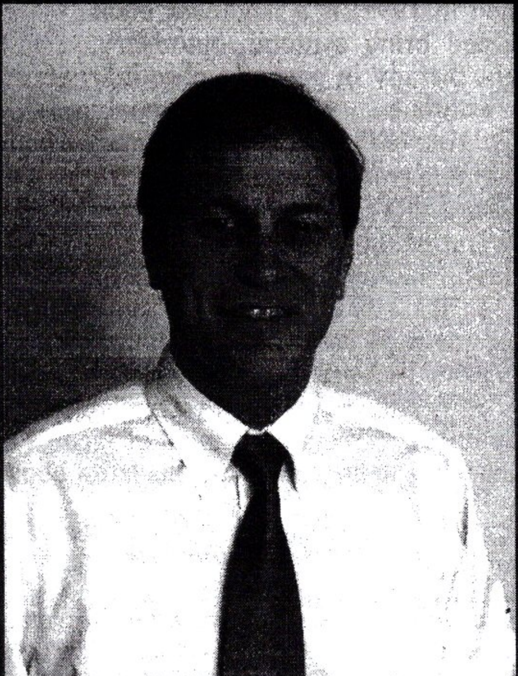

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