NeuroRegulation

Loss of an Eye: A Case Study of a First Responder's Neurofeedback Treatment

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Abstract

A case study is presented of a first responder injured in the line of duty who experienced the loss of an eye and sought neurofeedback treatment. That there are no known studies reporting qEEG or ERP findings, nor the efficacy of neurofeedback for the condition, emphasizes the importance of reporting on this case. A literature review of neuroanatomical and neurophysiological studies relevant to the loss of binocular vision is presented with application to the case at hand. Hypotheses regarding the measurable effects of monovision on qEEG and ERP assessments, and the possible efficacy of neurofeedback treatment, are explored in light of the findings. Possible improvements in visual processing were found after a course of neurofeedback treatment as measured by pre-post qEEG and ERP assessments.

Keywords: EEG; ERP; qEEG; neurofeedback; first responders; eye injury

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Introduction

This compelling case of a person in their thirties employed as a first responder began with an eye injury sustained during the course of duty which resulted in complete loss of sight in one eye and subsequent surgical removal of the eyeball. Fortunately, there was no encroachment of the trauma into the brain. The individual was referred for a quantitative electroencephalogram (qEEG) and event-related potentials (ERP) workup and neurofeedback (NFB) treatment. Approximately 1 month following the injury presented for the initial assessment. The individual had been medically cleared to return to work, with some limitations due to the effects of monocular vision and the sudden loss of binocular vision—namely on reduced peripheral vision and depth perception. The individual was also medically cleared to drive. In addition to the physical injury, there were concerns over the psychological impacts of the injury, so mental health checklists were also administered. The subject and clinicians agreed that the case was of research interest due to the rare opportunity to study the effects of the loss of binocular vision on qEEG/ERP measurements as well as to measure the effect of NFB treatment. While there was no qEEG/ERP data collected on the subject prior to the injury, we fortuitously had qEEG/ERP samples of many of the person's first responder cohort, which served as a comparison. Finally, two normative databases were employed, giving a comparison to theoretical healthy subjects.

In this paper we will analyze the data collected on the subject as well as research on potential NFB approaches for individuals experiencing similar injuries. Additionally, a review of pertinent neuroanatomical and neurophysiological literature will be reviewed.

First Responders

First responders are defined by 2003 presidential directive as "individuals who in the early stages of an incident are responsible for the protection and preservation of life, property, evidence, and the environment, including emergency response providers" (Johnson, 2007). Historically, the work of first responders has been considered to pose to them a higher risk for injury and death. To assess the occupational risks for first responders, Reichard and Jackson (2010) compiled various agency reports on the respective classifications of emergency medical services (EMS), fire, and law enforcement showing how these groups are at significant risk for work-related injuries. They estimated that police officers and career firefighters have the highest rates of injuries among first responders at 8.5% and 7.4% of the respective workforces (Reichard & Jackson, 2010).

Statistics for specific types of injuries for first responders are difficult to ascertain, possibly due to reporting limitations and inconsistencies. For example, Reichard and Jackson (2010) found a lack of unanimity among reporting criteria and no specificity about eye injuries, with the nearest classification being injuries to the face. Of interest for this study, statistics for assaults on law enforcement offices in Australia from 2014 to 2020 show that approximately 0.3% of injuries sustained from an assault result in eye disorders (Orr et al., 2023). The Centers for Disease Control and Prevention estimates that the risk of eye injury is 1.2% of all injuries sustained by workers in the general population, with no classification for first responders (Centers for Disease Control and Prevention, 2022).

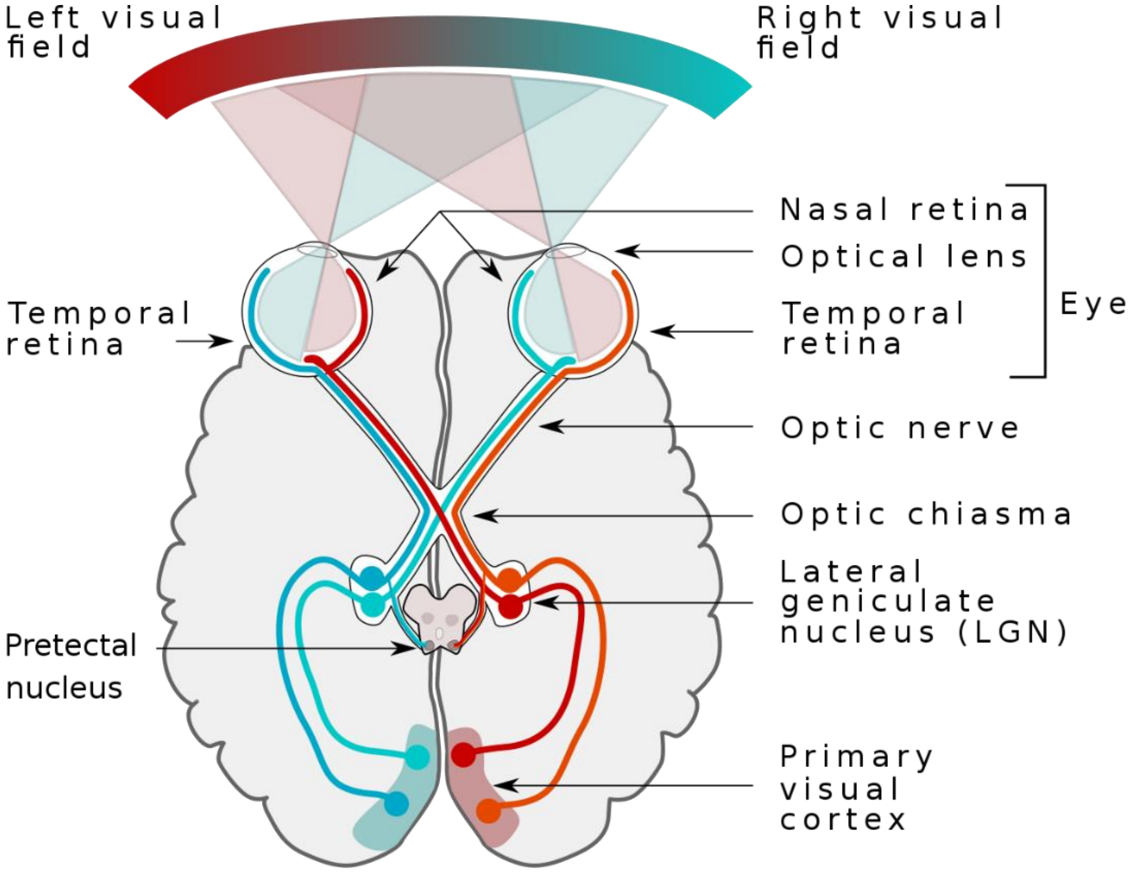
While the injury sustained by the subject of this study may or may not be representative of others in the field, the opportunity to study qEEG and ERP measurements may provide some insight into the nature of monocular vision after a sudden loss of binocular vision. Additionally, the effect of the chosen NFB protocol may provide important data as well.

The goals for NFB treatment were twofold: to address any posttraumatic stress and to enhance visual processing. While the literature is replete with research and evidence-based protocols for treating posttraumatic stress, a literature review returned no studies on treating vision loss from such an injury with NFB. A review of relevant neuroanatomical and neurophysiological aspects of vision gave limited guidance on appropriate NFB targets. As part of the retrospective analysis of the qEEG, ERP, and NFB data, and further literature review, additional insights were gained which may form the basis for additional treatment and study.

The Visual System

The human visual system involves levels of duplication and division of resources (see Figure 1). Roughly speaking, visual perception may be said to begin with the focus of photons from external sources on the retina with the light from the right visual field being refracted through the cornea and lens onto the left side of the retina, and vice versa with the left visual field. Ostensibly because the nose blocks the way, an arc of the far-right visual field is only accessible to the right eye, and vice versa with the far-left visual field to the left eye. The optic nerve conveys the sensory information from the retina to the lateral geniculate of the thalami where it is then sent to the primary visual cortex. En route from the retinas, tracts of the optic nerve route through the optic chiasm. Some tracts of the optic nerve are then routed to the thalamus of the same hemisphere with projections onto the visual cortex of the same hemisphere. Other tracts of the optic nerve make a crossover at the optic chiasm and are then routed to the thalamus of the opposite hemisphere with projections onto the visual cortex of that hemisphere. Projections from the left thalamus go to the left visual cortex and projections from the right thalamus to the right visual cortex. The result is that the input from the left side of the retina (right visual field) of the left eye (left temporal hemiretina) proceeds to the left thalamic lateral geniculate with information then passed on to the left visual cortex, and the input from the right side of the retina (left visual field) of the right eye (right temporal hemiretina) proceeding to the right thalamic lateral geniculate with information then passed on to the right visual cortex. The sensory input from the right side of the retina of the left eye (left nasal hemiretina) crosses over to the right thalamic lateral geniculate with information then passed on to the right visual cortex. Conversely, input from the right nasal hemiretina flow to the left thalamic lateral geniculate with information then passed on to the left visual cortex. The result is that sensory information for both the right and left visual fields is duplicated into the right and left visual cortices, respectively (Wurtz & Kandel, 2000).

Figure 1. *A Simplified Schema of the Human Visual Pathway*.



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Sensory input from the thalami into the visual cortices has an added level of complexity in that the tracts from the left and right sides of the retinas remain segregated in the thalamic lateral geniculate nuclei via magnocellular (M) and parvocellular (P) layers, which then form parallel pathways to different locations of the respective visual cortex (see Figure 2). The cells in the M and P pathways respond differently to color contrast, with the P cells being more sensitive to changes in colors and the M cells more sensitive to the luminance contrast (brightness) of the colors. In addition, P cells are more sensitive to spatial changes while M cells are more sensitive to temporal changes. Moreso, optic nerve tracts carry input from regions of the retina which are populated with rods and cones, which varying degrees of sensitivity to light and color, respectively, with higher densities of cones in the fovea, where spatial acuity is highest (Wurtz & Kandel, 2000).

The axonal tracts from the thalami lateral geniculate nuclei to the respective regions of the visual cortices have been mapped in some detail (Avarez et al., 2015). At the visual cortices in the medial occipital lobes, a representation of visual stimuli is plotted like a matrix corresponding to areas of the retinas (Larsson & Heeger, 2006; Tootell et al., 1998; Wurtz & Kandel, 2000; see Figure 3).

Figure 2. *A Less Simplified Schema of the Human Visual Pathway*.

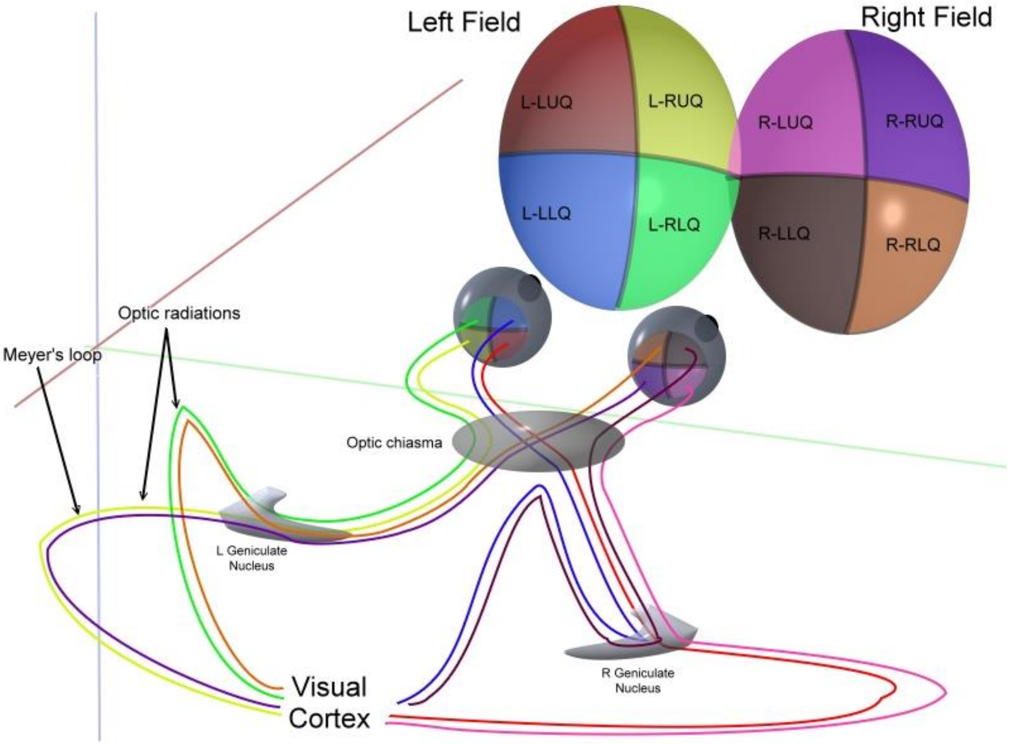

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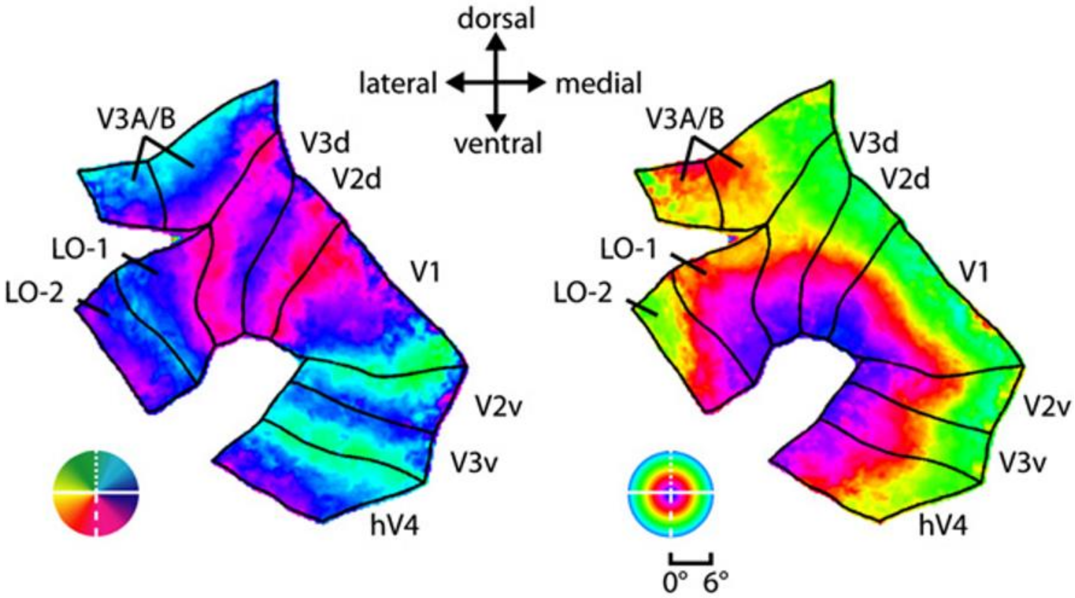
Figure 3. *Human Retinotopic Map*.



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Hypothesis 1: Measurable Effects

While the qEEG—as normed against a database of healthy subjects—can provide significant information regarding the brain's activity in a resting state, ERPs may be of much greater utility for assessing our subject's visual processing (Woodman, 2010). The hypothesis posited here is that even though our subject's monocular vision would be represented in both hemispheres in a way comparable to binocular vision, the amount of the sensory input would be halved, and the reduced input would be reflected in the ERPs, and possibly in the qEEG. This hypothesis might be supported in the literature of luminance perception, which indicates that attention is more influenced by luminance contrast as measured from lower to higher luminance levels (perceived as brightness; Eroğlu et al., 2020; Fimreite et al., 2015; Martinovic et al., 2011; Skiba et al., 2014). These luminance studies, however, were based on subjects' binocular vision and not specifically applicable to the focus of this study.

It is known that deprivation of sight in one eye early in life, such as with amblyopia, produces profound developmental differences in the related visual systems, namely, a depression of visual neurophysiology occurs for the deprived eye. Conversely, it has been shown that the visual system related to the nondeprived eye takes over and compensates (even to the extent of greater acuity). Most of the studies found which addressed the effects of monocular deprivation have focused on the effects of amblyopia. In the case of amblyopia, however, there is not a complete loss of vision in the affected eye, but a reduction in spatial detail (Freeman, 2009; Freeman & Bradley, 1980).

Lunghi et al. (2015) studied pre–post visual evoked potentials (VEP) following 150 min of monocular deprivation using a translucent patch over the nondominant eye. They reported an increased VEP in the deprived eye and decreased VEP in the nondeprived eye. Likewise, evoked alpha power increased in the deprived eyes and decreased for the nondeprived eye. EEG sites of interest were Cz, Pz, Poz, Oz, PO7, and PO8 (central, parietal, and occipital).

Kwon et al. (2009) studied pre–post fMRI BOLD responses in the visual cortices (V1 and V2) when subjects were fitted with contrast-reducing goggles for 4 hr. The result was an increase in BOLD responses in visual cortices, which supported a theory that prolonged deprivation from normal contrasts results in compensatory changes.

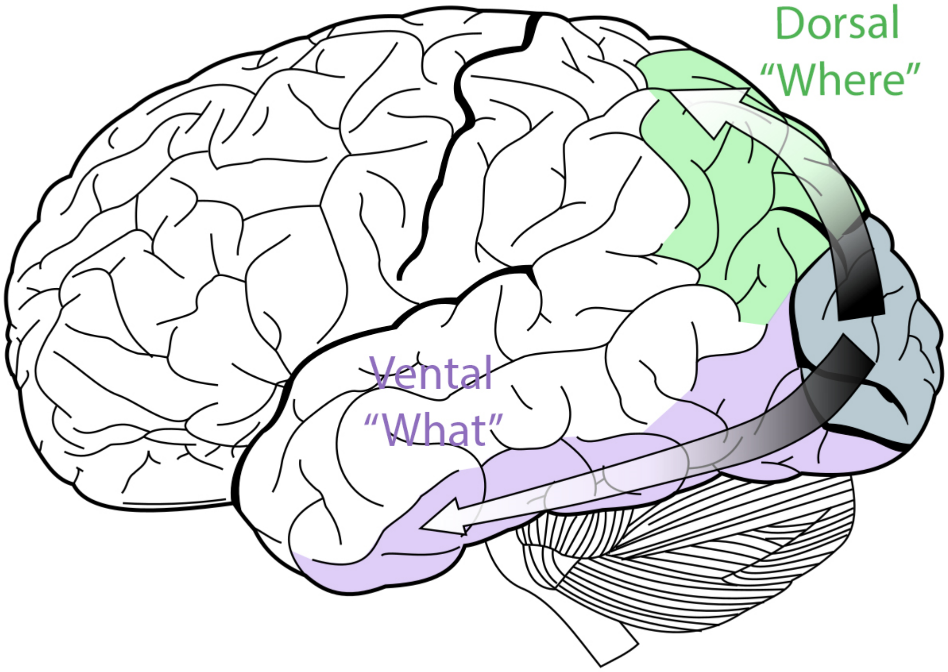
Studies showing the effects of totally obscuring vision in one eye are scarce. Frenkel and Bear (2004) chemically blinded one eye in adolescent mice and reported a potentiation of responses driven by the unblinded eye. These effects resembled similar procedures for adult mice. Rittenhouse et al. (1999) had previously demonstrated that the nondeprived eye potentiation was greater when mice were temporarily exposed to monocular deprivation using eyelid sutures than when the eye was chemically blinded for the same time period. This indicates that some level of low light gradient with low contrast (through eye lids) has an additive effect on the development of nondeprived eye dominance. We may assume, therefore, that total blindness of one eye has a potentiation effect on vision with the remaining eye, but perhaps not to the extent as with partial blindness such as the loss of contrast discrimination. So, even though the visual input is halved at the level of ocular input, the visual system is likely to compensate with increased potentiation, and possible increased acuity.

Hypothesis 2: Benefits From Neurofeedback

At the initial assessment it was clear that the subject's interest was in performance enhancement due to the significance of stringent demands of the vocation. Furthermore, the subject denied any psychological problems associated with the injury, as surprising as this was to the clinicians. A second hypothesis, then, was that NFB geared toward enhancing visual processing may serve the subject's desire to improve performance, given the limitations of depth perception and peripheral vision. Numerous potential protocol targets were considered, including amplitude training (beta enhancement) over occipital, parietal, or posterior temporal sites to enhance visual processing. In addition, coherence training was considered to be an option in this regard.

Returning to the neuroanatomical discussion to inform our strategy for determining a protocol, from the thalamic lateral geniculate nuclei, the distinct parallel M and P pathways set the stage for some of the ways visual input is processed once it reaches the visual cortices in the occipital lobes, and ultimately how the sensory information is processed downstream by related brain structures. At this point, two distinct circuits might be affected, namely the dorsal and ventral streams (Goodale & Milner, 1992) which have been labeled as generally involving a determination of the "what" (ventral) and the "where" (dorsal; see Figure 4). Joel Norman elaborated on the two-pathway model as including the respective functions of the streams as recognition and identification (ventral) and visually guided behavior (dorsal) with the source input for the streams as foveal (ventral) and retinal-wide (dorsal). He further posited that the ventral stream is less affected by monocular vision (Norman, 2002). More recent studies have shown a dynamic interplay between various aspects of the dorsal and ventral streams (Alvarez et al., 2015) which is also highly contextual (Gilbert & Li, 2013). An earlier study by Zanon et al. (2010) demonstrated that activating the left parietal cortex with transcranial magnetic stimulation (TMS) activated both the dorsal and ventral with prefrontal regions streams as measured by EEG ERPs.

Figure 4. *Ventral and Dorsal Visual Streams*.



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No NFB studies were found that specifically addressed monocular vision. An EEG NFB study to address visuospatial neglect of right hemisphere stoke patients using alpha power downtraining in the parietal region demonstrated a promising improvement in visuospatial search measurements (Ros et al., 2017). Of interest are fMRI NFB experiments demonstrating control over subject-specific regions of the retinotopic visual cortex with measured enhancement of visual perceptual sensitivity (Schamowski et al., 2012; Shibata et al., 2011; Wang et al., 2021).

Methods

The Subject

To protect the identity of the subject, no exact age, gender identity, or job title is given. The subject is in his or her thirties and is a first responder. The subject gave written consent for his or her data to be used for the purpose of research. This study complies with the Declaration of Helsinki and was performed according to ethics committee approval.

Symptom Assessments

The Achenbach Behavior Checklist (ASEBA) Adult Self-Report and Zung Self-Rating Anxiety Scale were administered at pretreatment and posttreatment.

EEG and ERP Recordings

For each assessment session, eyes-closed and eyes-opened resting state EEG data for the subject was recorded for 5 min, respectively, and a Visual Continuous Performance Test (VCPT) ERP recording for 20 minutes, from 19 electrode locations (Fp1, Fp2, F3, F4, F7, F8, Fz, C3, C4, Cz, P3, P4, Pz, T3, T4, T5, T6, O1, and O2) positioned on the scalp according to the international 10/20 system using a standardized electrode cap (Electro-Cap International, Inc., Eaton, Ohio, USA) with a linked-ears reference (see Figure 5).

Preparation of electrodes was performed in a manner adequate to achieve impedance levels of less than 5,000 ohms (Jones, 2015). An ECG channel was also collected to assist with identifying ECG artifacts. Recordings were made with a Mitsar 201 high-impendence 21 channel amplifier with WinEEG version 2.136.109 software (Mitsar Co. Ltd., St. Petersburg, Russia) using a Windows-based laptop. The ERP visual continuous performance test (VCPT) was administered using the included PsyTask version 1.55.19 presentation software on an ethernet cable-connected second Windows-based laptop with calibration done according to the manufacturer's specifications.

Figure 5. *Eyes-Open EEG*.

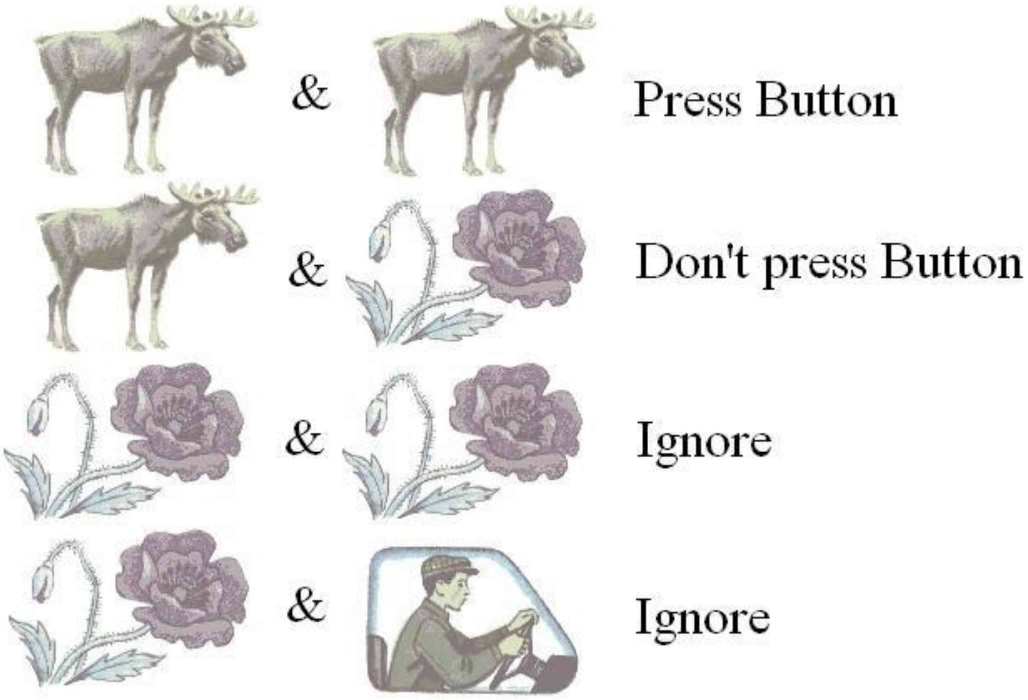
Note. Sample of 19 channel eyes open EEG showing unilateral eye movements during blinks.

The VCPT trials were set up to present go/no-go trials in which a subject is presented with two images, each displayed on screen consecutively, one second apart. The images are of animals, flowers, and people. The go condition is comprised of two animals in sequence. The no-go condition is comprised of an animal followed by a flower. Other presentations are interspersed which entail the presentation of a flower followed by a flower and a flower followed by a person with a tone sounding simultaneously with the image of a person. An example of this schema is shown in Figure 6.

qEEG and ERP Processing

qEEG processing was accomplished using WinEEG software and the Human Brain Index normative database (HBimed AG, Switzerland) and NeuroGuide version 3.0.4 software and the LifeSpan normative database (Applied Neuroscience, Inc., Largo, FL). ERP processing was done using WinEEG and the Human Brain Index normative database.

Figure 6. *ERP VCPT Visual Stimuli*.



Note. “Press Button” is the go condition whereas “Don’t press Button” is the no-go condition.

Neurofeedback

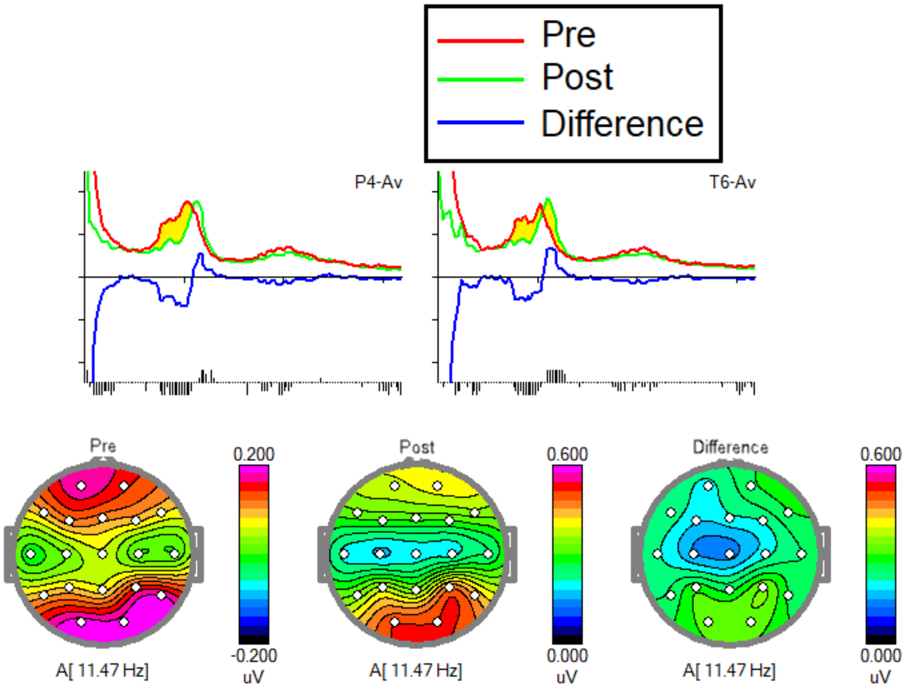
NFB sessions were conducted using BioExplorer software (CyberEvolution, Inc., Seattle, WA) with the Neurobit Optima+4 high impedance amplifier (Neurobit Systems, Poland). Preparation of electrodes was performed in a manner adequate to achieve impedance levels of less than 5 kΩ (Jones, 2015). The subject received a total of eight sessions of NFB training: two sessions per week for 4 weeks. Two-channel amplitude training was accomplished with active electrodes at P3 and P4, with reference electrodes placed at A1 and A2, respectively. The ground electrode was placed at Cz. Placements on the scalp were in accordance to the International 10-20 system. Gold-plated Grass electrodes were used (Natus Medical, Inc., Middleton, Wisconsin, USA). Frequency bands trained were 4–10 Hz (decrease), 12–18 Hz (increase), and 25–35 Hz (decrease). Operant-conditioning audio-visual feedback was provided using screen brightening and volume increase as positive reinforcement while the subject watched cartoon animations, by manually adjusting the individual frequency band thresholds at equal levels of success in order to maintain and an average overall success percentage at approximately 50–60%.

Results

Salient differences in the pre–post qEEG measures as processed with WinEEG/HBI indicated that (a) the occipital alpha rhythm peak frequency was faster after the completion of the NFB regimen, from 10.5 Hz to 11.2 Hz, with an inhibition of low frequency content of the posterior alpha, and (b) the increased level of the posterior cortex activation after the NFB sessions (see Figure 7).

Pre–post calculations in NeuroGuide/LifeSpan found a similar increase in the alpha peak frequency, from 9.94 Hz to 10.44 Hz at O1 and O2 (see Table 1). The decrease in alpha 1 (8–10 Hz) activity was also statistically significant (*p* < .001).

Figure 7. *Pre- and Post-qEEG Spectra in Eyes-Closed Condition*.



Note. WinEEG and HBI.

Table 1
Pre–Post Changes in Alpha Peak Frequency

Pre–Post	Site	APF (Hz)	
Pre	O1	9.91	
Pre	O2	9.97	
		9.94	Average
Post	O1	10.44	
Post	O2	10.44	
		10.44	Average
		0.5	**Difference**

Note. NeuroGuide.

Behavior characteristics that reflect response accuracy, response time (RT) in milliseconds (ms), and variability of RT (in ms) were captured during the ERP trails. Norms for these measures are included in the database. This potentially gives a picture of a subject's ability to accurately identify the stimuli and respond accordingly, and the speed with which the subject responds—from the time of the stimulus presentation to the time of response (clicking the button). Furthermore, by comparing behaviors during both the pre- and posttreatment assessment, a probable measure of treatment effects on response characteristics is obtained. During this subject's ERP trials, pre- and posttreatment errors were zero, and response time (RT) and RT variability decreased at the postassessment. All posttreatment measures were below the normative database average (Table 2).

Table 2
Pre- and Post-ERP Behaviors

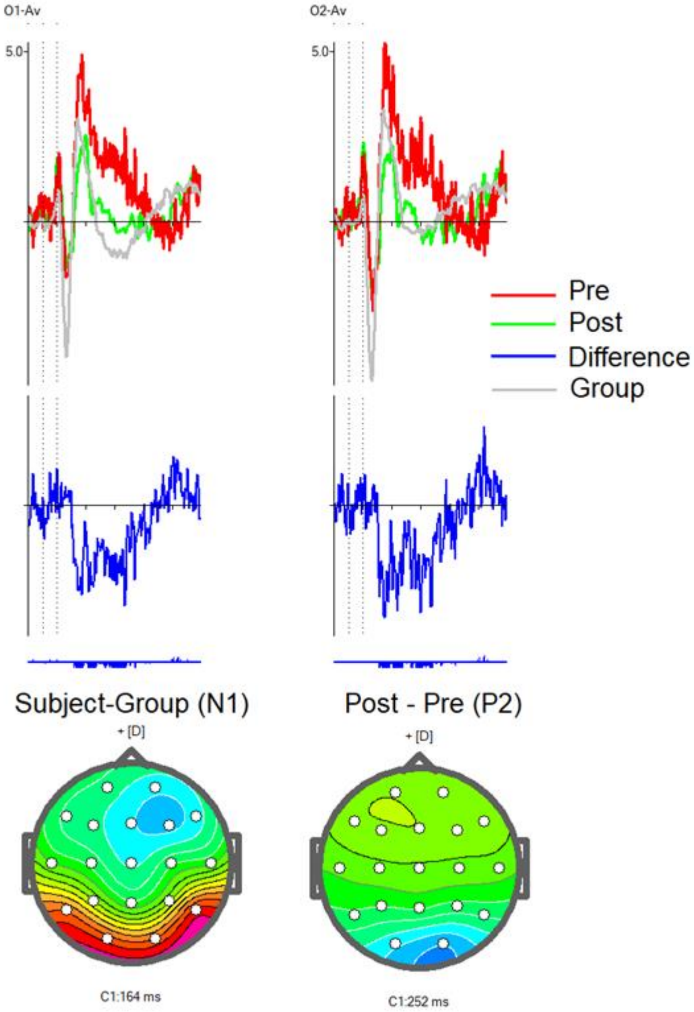
Pre–Post	Omission Errors	Commission Errors	Response Time (ms)	Variability (RT)
Pre	**0**	**0**	**430**	**8.3**
Post	**0**	**0**	**363**	**4.1**
Norm	**1.9**		**379**	**6.8**

Note. WinEEG and HBI.

In examining pre- and posttreatment responses to the first visual stimulus in go (a*) trials, additional comparisons were made to the normative database and to a group of the subject's peers which was conducted in an earlier study, as shown in Figure 8.

The visual N1 wave of occipital temporal topography (see the left map), reflecting the level of the ventral stream activation, is significantly reduced in comparison to the group norms. This result probably reflects the effect of the injured eye. Before the NFB sessions, a late positive component of the ERP in the occipital sites (O1, O2) is abnormally increased. This result probably reflects the increased sensitivity of neurons participating in formation of the poststimulus visual trace. But this late component is significantly reduced after NFB, possibly reflecting a normalization of the component—and an improvement in ventral stream function. If so, the subject's ability to process the "what" in visual processing may have been improved.

Figure 8. *ERPs in the Cued Go/No-Go Task*.



Note. WinEEG and HBI.

Surprisingly, the subject's pre- and posttreatment symptom checklists were within normal limits. All of the ASEBA scales, for example, were below clinical levels. The Zung anxiety scale results were in the normal range, as well. The reason for normal symptomatology following a traumatic event is unknown but may be attributed to the intense level of training the subject had received and her or his level of resilience.

Conclusions

Case studies can be of value when a clinician provides assessment and treatment in a highly unusual situation and may yield insights unobtainable through conventional research methods. This study examined a unique case in which a first responder's loss of an eye is hypothesized to cause reduced visual processing which may be measurable with qEEG and ERP assessments. Relevant findings were presented. In addition, the study examines the possibility of enhancing subsequent visual processing in the case of sudden injury-related monovision by the application of parietal amplitude-based NFB. Pre- and posttreatment analysis of certain ERP markers were presented that may indicate the efficacy of NFB in this regard.

Limitations of the study include the fact that only one subject is studied. This is due, for the most part, to the rarity of the situation. An internet search shows that there may be a few additional somewhat similar cases related to first responders occurring on an infrequent basis, which conceivably may yield a broader population to study.

That the subject's pre- and posttreatment ERP components reflect a plausible improvement, or normalization, of the ventral stream, these changes cannot be attributed solely to the NFB provided. Research was presented in the literature review that indicates the possibility of the brain's ability to adapt to the loss of an eye with the improvement to certain aspects of visual processing. The mere passage of time may therefore account for the documented improvements as spontaneous neuroplastic changes are more significant during the early months following an injury. On the other hand, early intervention may enhance functional recovery. In this case, a highly motivated, high-functioning individual demonstrated improvements that may not be seen across the general population.

As clinicians develop treatment protocols for injured public servants, it is hoped that this study may shed some light on similar cases. As for this subject, future possibilities for EEG NFB may include further beta enhancement amplitude training of the parietal, occipital, or temporal-parietal regions. Additionally, the parietal alpha suppression protocol studied by Ros et al. (2017) is of interest for addressing any visuospatial issues. The study by Zanon et al. (2010) suggested possibilities for parietal-prefrontal coherence training as a means of enhancing dorsal and ventral visual streams. And finally, the cited fMRI studies, demonstrating subject's ability to control visual cortex activity with resulting improvement in visual perceptual sensitivity (Scharnowski, 2012; Shibata et al., 2011; Wang et al., 2021) and concomitant EEG LORETA studies demonstrating motor imagery localization (Cebolla, et al., 2017) may provide a rationale for LORETA ROI NFB which enables the targeting of the visual cortices with source localization methods.

Author Disclosure

Authors have no grants, financial interests, or conflicts to disclose.

References

Alvarez, I., Schwarzkopf, D. S., & Clark, C. A. (2015). Extrastriate projections in human optic radiation revealed by fMRI-informed tractography. *Brain Structure and Function, 220*(5), 2519–2532. https://doi.org/10.1007/s00429-014-0799-4

Applied Neuroscience, Inc. (2016). NeuroGuide (Version 3.0.4) [Computer software].

Cebolla, A.-M., Palmero-Soler, E., Leroy, A., & Cheron, G. (2017). EEG spectral generators involved in motor imagery: A swLORETA study. *Frontiers in Psychology, 8*, Article 2133. https://doi.org/10.3389/fpsyg.2017.02133

Centers for Disease Control and Prevention (2022). *Work-related injury statistics query system*. U.S. Department of Health & Human Services. https://wwwn.cdc.gov/Wisards/workrisqs/workrisqs_estimates_results.aspx

Electro-Cap International, Inc. (n.d.). Electro-Cap 19-channel system [Apparatus].

Eroğlu, K., Kayıkçıoğlu, T., & Osman, O. (2020). Effect of brightness of visual stimuli on EEG signals. *Behavioural Brain Research, 382*, 112486–112486. https://doi.org/10.1016/j.bbr.2020.112486

Fimreite, V., Ciuffreda, K. J., & Yadav, N. K. (2015). Effect of luminance on the visually-evoked potential in visually-normal individuals and in mTBI/concussion. *Brain Injury, 29*(10), 1199–1210. https://doi.org/10.3109/02699052.2015.1035329

Freeman, R. D. (2009). Visual deprivation. In L. R. Squire (ed.), *Encyclopedia of neuroscience* (pp. 277–282). https://doi.org/10.1016/B978-008045046-9.00928-1

Freeman, R. D., & Bradley, A. (1980). Monocularly deprived humans: Nondeprived eye has supernormal vernier acuity. *Journal of Neurophysiology, 43*(6), 1645–1653. https://doi.org/10.1152/jn.1980.43.6.1645

Frenkel, M. Y., & Bear, M. F. (2004). How monocular deprivation shifts ocular dominance in visual cortex of young mice. *Neuron, 44*(6), 917–923. https://doi.org/10.1016/j.neuron.2004.12.003

Gilbert, C. D., & Li, W. (2013). Top-down influences on visual processing. *Nature Reviews Neuroscience, 14*(5), 350–363. https://doi.org/10.1038/nrn3476

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Johnson, T. A. (Ed.). (2007). Homeland security presidential directive/HSPD-8. In *National Security Issues in Science, Law, and Technology* (pp. 587–588). CRC Press. https://doi.org/10.1201/9781420019087

Jones, M. S. (2015). Comparing DC offset and impedance readings in the assessment of electrode connection quality. *NeuroRegulation, 2*(1), 29–36. https://doi.org/10.15540/nr.2.1.29

Kwon, M. Y., Legge, G. E., Fang, F., Cheong, A. M. Y., & He, S. (2009). Adaptive changes in visual cortex following prolonged contrast reduction. *Journal of Vision, 9*(2):20, 1–16. https://doi.org/10.1167/9.2.20

Larsson, J., & Heeger, D. J. (2006). Two retinotopic visual areas in human lateral occipital cortex. *The Journal of Neuroscience, 26*(51), 13128–13142. https://doi.org/10.1523/JNEUROSCI.1657-06.2006

Lunghi, C., Berchicci, M., Morrone, M. C., & Di Russo, F. (2015). Short-term monocular deprivation alters early components of visual evoked potentials. *The Journal of Physiology*, *593*(19), 4361–4372. https://doi.org/10.1113/JP270950

Martinovic, J., Mordal, J., & Wuerger, S. M. (2011). Event-related potentials reveal an early advantage for luminance contours in the processing of objects. *Journal of Vision, 11*(7), Article 1. https://doi.org/10.1167/11.7.1

Mitsar, Ltd. (n.d.). Mitsar EEG 201 system [Apparatus].

Mitsar, Ltd. (n.d.). PsyTask (Version 1.55.19) [Computer software].

Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *Behavioral and Brain Sciences, 25*(1), 73–96. https://doi.org/10.1017/S0140525X0200002X

Orr, R., Canetti, E. F. D., Pope, R., Lockie, R. G., Dawes, J. J., & Schram, B. (2023). Characterization of injuries suffered by mounted and non-mounted police officers. *International Journal of Environmental Research and Public Health, 20*(2), Article 1144. https://doi.org/10.3390/ijerph20021144

Reichard, A. A., & Jackson, L. L. (2010). Occupational injuries among emergency responders. *American Journal of Industrial Medicine, 53*(1), 1–11. https://doi.org/10.1002/ajim.20772

Rittenhouse, C. D., Shouval, H. Z., Paradiso, M. A., & Bear, M. F. (1999). Monocular deprivation induces homosynaptic long-term depression in visual cortex. *Nature, 397*(6717), 347–350. https://doi.org/10.1038/16922

Ros, T., Michela, A., Bellman, A., Vuadens, P., Saj, A., & Vuilleumier, P. (2017). Increased alpha-rhythm dynamic range promotes recovery from visuospatial neglect: A neurofeedback study. *Neural Plasticity*, 2017, Article 7407241. https://doi.org/10.1155/2017/7407241

Scharnowski, F., Hutton, C., Josephs, O., Weiskopf, N., & Rees, G. (2012). Improving visual perception through neurofeedback. *The Journal of Neuroscience, 32*(49), 17830–17841. https://doi.org/10.1523/JNEUROSCI.6334-11.2012

Shibata, K., Watanabe, T., Sasaki, Y., & Kawato, M. (2011). Perceptual learning incepted by decoded fMRI neurofeedback without stimulus presentation. *Science, 334*(6061), 1413–1415. https://doi.org/10.1126/science.1212003

Skiba, R. M., Duncan, C. S., & Crognale, M. A. (2014). The effects of luminance contribution from large fields to chromatic visual evoked potentials. *Vision Research, 95*, 68–74. https://doi.org/10.1016/j.visres.2013.12.011

Tootell, R. B. H., Hadjikhani, N. K., Mendola, J. D., Marrett, S., & Dale, A. M. (1998). From retinotopy to recognition: fMRI in human visual cortex. *Trends in Cognitive Sciences, 2*(5), 174–183. https://doi.org/10.1016/S1364-6613(98)01171-1

Wang, Z., Tamaki, M., Frank, S. M., Shibata, K., Worden, M. S., Yamada, T., Kawato, M., Sasaki, Y., & Watanabe, T. (2021). Visual perceptual learning of a primitive feature in human V1/V2 as a result of unconscious processing, revealed by decoded functional MRI neurofeedback (DecNef). *Journal of Vision, 21*(8):24, 1–15. https://doi.org/10.1167/jov.21.8.24

Woodman, G. F. (2010). A brief introduction to the use of event-related potentials in studies of perception and attention. *Attention, Perception, & Psychophysics, 72*(8), 2031–2046. https://doi.org/10.3758/APP.72.8.2031

Wurtz, R. H., & Kandel, E. R. (2000). Central visual pathways. In E. R. Kandel, J. H. Schwartz, H. James, & T. M. Jessell (Eds.), *Principles of neural science* (4th ed.). McGraw-Hill.

Zanon, M., Busan, P., Monti, F., Pizzolato, G., & Battaglini, P. P. (2010). Cortical connections between dorsal and ventral visual streams in humans: Evidence by TMS/EEG co-registration. *Brain Topography, 22*(4), 307–317. https://doi.org/10.1007/s10548-009-0103-8

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