INTRODUCTION

Stroke is one of the leading causes of death and disability in the adult population of the United States.\(^1\) Common risk factors include hypertension, diabetes, high cholesterol levels, smoking, and atrial fibrillation.\(^2\)

Stroke can either be ischemic or hemorrhagic. According to the American Stroke Association, 83% of strokes are ischemic, and 17% are hemorrhagic.\(^3\) Stroke produces an insufficient supply of oxygen (i.e., anoxia) via blood circulation to the affected brain cells. This oxygen deprivation causes insult and frequently death to the underlying brain tissues, with resulting impairment of its neurological control function.

Stroke frequently results in impaired visual functioning to a constellation of areas,\(^4,5\) such as reading and visual scanning ability. Visual-field defects (e.g., hemianopia), at times with visual neglect, are common visual sequelae to a stroke, or cerebrovascular accident (CVA).\(^6,7\) Hemianopia refers to a physiologically-based phenomenon involving loss of one-half of the lateral visual-field and for which the individual is fully aware of its absence. In contrast, visual neglect refers to a perceptually-based phenomenon in which the individual is “unaware” of the loss of one half of their lateral visual-field.\(^8\) Hemianopia and visual neglect can be present together, or independently. Either will adversely affect one’s activities of daily living (ADLs), as well as have an adverse impact on one’s vocational and avocational goals, and rehabilitative progress.\(^9\)

Since stroke patients with hemianopia frequently have fixational eye movement, attentional, and/or cognitive deficits, clinical visual field perimetry may not always be an

**Article: Assessing Hemianopia Objectively in Stroke Patients Using the VEP Technique: A Pilot Study**

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**ABSTRACT**

The purpose of this pilot study was to assess hemianopic visual field defects objectively in individuals with stroke using the pattern, visual-evoked potential (VEP) technique. Subjects were comprised of 5 adults with documented hemianopic visual field defects. The central field and the intact hemi-field VEP amplitudes were significantly larger than found in the hemianopic field (p < 0.05). However, latency values were similar (p > 0.05). The objective pattern VEP has the potential to be used rapidly and reliably to detect for the presence of hemianopic visual field defects in stroke patients.
optimal method to investigate for the presence of hemianopia.\textsuperscript{10,11} The VEP is a logical adjunct technique to assess for hemianopia in the CVA population. It is an objective, rapid, and repeatable method.\textsuperscript{11,12} Furthermore, it circumvents, or at least minimizes, many of the inherent problems associated with clinical visual field testing. The VEP method does not demand prolonged attention or highly accurate fixation, as compared to conventional perimetry, especially over a relatively long test duration (i.e., 5 minutes or more for perimetry versus 20 seconds for each VEP trial).

There are a paucity of relevant studies which have used the VEP method to assess hemianopia in CVA patients. The results are equivocal, as described below.

Viggiano et al\textsuperscript{13} studied 10 individuals with CVA having left-field hemianopia and visual neglect, 11 individuals with CVA having left-field hemianopia only, and 6 visually-normal subjects. In the first experiment, they used different check sizes (12, 14, 36, 48, and 72 min arc) with a constant temporal frequency of 4.76 Hz. In the second experiment, they used different temporal frequencies (1.96, 3.03, 4.76, 6.66, 8.33, and 16.66 Hz) with a constant check size of 48 min arc. Contrast was 87%, and luminance was 120 cd/m\textsuperscript{2}. The circular checkerboard stimulus (radius = 7.5 degrees) was presented both centrally, and in the near retinal periphery (8.5 degrees laterally). For both the central and near peripheral stimulus, there were no significant differences in the VEP amplitude between those hemianopes with versus without visual neglect. They speculated that the phenomenon of visual neglect was the result of damage to higher-level cortical areas, and not to early primary cortical areas encompassed by the underlying VEP signal region. However, they did not investigate latency, which may provide additional information regarding any delay in visual processing in these patients, as latency is typically slowed based on other test findings.\textsuperscript{14}

Similarly, Spinelli et al.\textsuperscript{15} used the steady-state VEP in 16 right-brain-injured, hemianopic stroke patients (i.e., 9 with left-visual field neglect, 7 without neglect), and 16 visually-normal subjects. Vertical sinusoidal gratings of 0.56 cycles per degree were used with a field size of 12.8H X 32.8V degrees. The gratings were sinusoidally-reversed at temporal frequencies ranging from 4-11Hz. Contrast was 32%, and luminance was 150 cd/m\textsuperscript{2}. They assessed both VEP amplitude and latency. There was no significant effect on either parameter in the neglected and normal hemifields. The same was true in hemianopic patients without neglect, as well as in the visually-normal subjects. However, they did find that the VEP amplitude was slightly lower at higher temporal frequencies (e.g., 8 Hz) in those with a neglected left-visual field, as compared to their normal right-visual field. Furthermore, with increase in temporal frequency, they found markedly delayed latencies of ~30-40 ms in patients with visual neglect, as compared to those without neglect. This study demonstrated that individuals with visual neglect did exhibit slowed visual processing in the visually-neglected field only, at least under highly specific stimulus conditions, in the primary visual cortex.

In contrast, Angelelli et al.\textsuperscript{16} measured steady-state VEP responses in 19 right brain-damaged (RBD) patients with left-sided hemianopia and visual neglect. They also had two controls groups: 15 left brain-damaged (LBD) patients and 12 right brain-damaged (RBD) patients, all with hemianopia but without visual neglect. They used vertical sinusoidal gratings of 0.56 cycles per degree with a central field size of 6H X 16V degrees. The gratings were sinusoidally-reversed at 10 temporal frequencies ranging from 4-10.5 Hz, with a central fixation target present. Contrast was 32%, and luminance was 150 cd/m\textsuperscript{2}. They assessed both amplitude and latency. Stimuli were presented either in the right (RVF) or left (LVF) visual field. They too found that the mean latency was significantly delayed by approximately 25 ms in the neglected LVF, as compared to the normal RVF, in those with RBD. In contrast, there was no significant difference in latency in either the right or left
hemifield in the RBD and LBD groups who did not have neglect. The VEP amplitudes were reduced in the hemianopic hemifield in the RBD patients, with or without neglect. However, the VEP amplitudes were similar in both hemifields in the LBD group. These results suggested that both visual-neglect and hemianopia could be detected, even at the level of the primary visual cortex (V1). These findings supported the notion that the VEP can be used clinically to detect and assess hemianopia and/or visual neglect in patients with CVA.

Based on the above 3 studies, the results are equivocal. Viggiano et al., Spinelli et al., found that it could. Furthermore, none of the studies used either low luminance and/or low contrast stimuli to assess hemianopia, which might be more sensitive to elicit presence of a visual field defect and/or visual neglect. Therefore, this area deserves to be explored, which might reveal more subtle differences early in the afferent visual pathway.

Thus, the purpose of the present pilot study was to determine if the VEP technique could be used to detect and assess hemianopia objectively and reliably in individuals with CVA/stroke. More specifically, the hypothesis is that the VEP approach will be able to detect and assess hemianopia objectively in individuals with stroke using more subtle stimuli, such as low contrast and low luminance patterns, which has never been tested before in this population.

**METHODS**

**Subjects**

Five individuals with CVA/stroke and hemianopia (mean age = 46.6 years, age range = 29 to 62 years) participated in this study: three with complete right hemianopia, one with complete left hemianopia, and one with incomplete left hemianopia. None had visual neglect; this diagnosis was as specified in the referring clinician’s record, and it was not reassessed by us in the present investigation. See Table 1 for subject demographics. They were referred with full medical documentation to the Raymond J. Greenwald Rehabilitation Center (RJGRC)/Brain Injury Clinic at the SUNY, State College of Optometry from rehabilitation professionals at the following institutions: Rusk Institute of Rehabilitative Medicine at NYU Medical Center, Bellevue Hospital at NYU Medical Center, Department of Rehabilitative Medicine at Mount Sinai Medical Center, Lenox Hill Hospital, New York Hospital, and the International Center for the Disabled. All had corrected visual acuity of 20/20 or better in each eye at both distance and near. Exclusion criteria included a history of seizures, constant strabismus, and amblyopia, as well as any

<table>
<thead>
<tr>
<th>Subject/ Age (years)/ Gender</th>
<th>Years since last stroke</th>
<th>Type of hemianopia</th>
<th>Visual Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1/47/M</td>
<td>23 years (stroke at 2 years of age due to arteriovenous malformation)</td>
<td>Right hemianopia</td>
<td>Reading problems</td>
</tr>
<tr>
<td>S2/29/F</td>
<td>1 year</td>
<td>Left incomplete-hemianopia</td>
<td>Reading problems, Migraines</td>
</tr>
<tr>
<td>S3/39/F</td>
<td>1 year</td>
<td>Left hemianopia</td>
<td>Reading problems, Migranes, Photosensitivity, Visual motion sensitivity</td>
</tr>
<tr>
<td>S4/56/F</td>
<td>24 years</td>
<td>Right hemianopia</td>
<td>Reading problems, Visual motion sensitivity</td>
</tr>
<tr>
<td>S5/62/F (first stroke 25 years ago)</td>
<td>Right hemianopia</td>
<td>Reading problems, Visual-attention deficit, Visual fatigue, Distance perception problem, Photosensitivity, Visual motion sensitivity</td>
<td></td>
</tr>
</tbody>
</table>

**Table 1: Demographics of stroke patients.**
type of ocular, neurological, and/or systemic disease, such as macular degeneration, multiple sclerosis, and diabetes, respectively. The study was approved by the Institutional Review Board (IRB) at the SUNY, State College of Optometry. Each subject provided written informed consent.

Apparatus

The Diopsys™ NOVA-TR system (Diopsys, Inc., Pine Brook, New Jersey, USA) was used to generate a checkerboard pattern stimulus and analyze the VEP data. Three Grass gold-cup electrodes (Grass Technologies, Astro-Med, Inc., West Warwick, RI), each of 1 cm in diameter, were placed on the scalp to measure the VEP responses. Since individuals with stroke frequently exhibit fixational impairment necessitating corrective saccades that may create artifacts in the recordings, the DIOPSYS software incorporates an automated artifact detector. If more than 5 artifacts are detected during a trial, this record is excluded from the analysis. While only one check size was used (i.e., 20 min arc), this check size has been found to be optimal in our laboratory. Details have been provided elsewhere.

Stimulus

The VEP amplitude and latency were assessed with binocular viewing and full distance refractive correction in place under the following three experimental conditions (See Figure 1). None of the subjects reported the VEP stimulus to be blurry. These three stimulus conditions produced the most reliable VEP response out of the possible combinations. Three trials for each test condition were performed:

I. Central field [high contrast (HC) and high luminance (HL), low contrast (LC) and high luminance (HL), low luminance (LL) and high contrast (HC)] – A standard, central, checkerboard pattern (17H X 15V degrees, 20 min arc check size at 1 meter, 20 second test duration, temporal frequency 1 Hz = 2 reversal/second) with a central fixation (0.5º diameter) target was used as the baseline comparison stimulus. A checkerboard pattern with either low or high contrast levels (i.e., 20 and 85%), and with either low or high luminance levels (i.e., 7.4 and 74 cd/m²), was presented for each stimulus combination.

II. Intact hemi-field only (HC/HL, LC/HL, LL/HC) – In this condition, the checkerboard pattern was presented only to the intact hemianopic visual-field (8.5H X 7.5V degrees) with the contrast and luminance levels as described in #I above. The other half of the visual field (i.e., the hemianopic field) was presented with a blank, non-patterned stimulus field (luminance 1.27 cd/m²), as used in our earlier study.

III. Hemianopic field only (HC/HL, LC/HL, LL/HC) – In this condition, the checkerboard pattern was presented only
to the hemianopic field (8.5 H X 7.5 V degrees) with the contrast and luminance levels as mentioned above in #I. The other half of the visual-field (i.e., intact) was presented with a blank, non-patterned stimulus field (luminance 1.27 cd/m2), as used in our earlier study.

**DATA ANALYSIS**

An average of the three trials for each of the three visual field test conditions (i.e., complete, intact, and hemianopic), and three stimulus combinations (i.e., HC/HL, LC/HL, LL/HC), was initially calculated for each subject. Then, for each subject, the trial for which the VEP response exceeded 1 SD from the mean was deleted to remove this outlier; and, in the case where all 3 trial values were within 1 SD, the most deviant trial response value was deleted. The mean and SD for the 2 remaining trials were calculated and used for analysis of the group mean VEP amplitude and latency. A one-way, repeated-measures ANOVA was performed for each condition using GraphPad Prism 5.04 software. Graphical displays were also prepared with the same software. Conventional clinical perimetric findings (Humphrey 24-2) were available from the medical records, except for subject S1 (Figure 2).

VEP repeatability was assessed in subject S5. The same test conditions were repeated one week later. The coefficient of variation (CV = standard deviation of the multiple sessions for each condition divided by the mean of these multiple sessions for each condition) was calculated to assess for repeatability of the VEP responses. The CV value can range from 0.00 to 1.00. This value represents the intra-subject, inter-session variability; the smaller the value, the less the variability, and the better the repeatability.

**RESULTS**

**Group Data Amplitude**

Figure 3A presents the group mean VEP amplitude for the central, intact, and hemianopic visual fields for the following three stimulus combinations: high contrast (HC) and high luminance (HL), low contrast (LC) and high luminance (HL), and low luminance (LL) and high contrast (HC). A one-way ANOVA for the factor of visual field at HC/HL was significant [F (2, 12) = 10.18, p < 0.05]. The post-hoc Tukey test results revealed that the amplitudes for the central and intact hemifields were significantly larger than for the hemianopic field (p < 0.05). A one-way ANOVA for the factor of visual field at LC/HL was significant [F (2, 9) = 5.88, p < 0.05]. The post-hoc Tukey test results revealed that the amplitude for the central field was significantly larger than for the hemianopic field. A one-way ANOVA for the factor of visual field at LL/HC was significant [F (2, 12) = 10.18, p < 0.05]. The post-hoc Tukey test results revealed that the amplitudes for the central and intact hemifields were significantly larger than for the hemianopic field (p < 0.05).
**Latency**

Figure 3B presents the group mean VEP latency (P 100 ms) for the central, intact, and hemianopic visual fields for the following three stimulus combinations: HC/HL, LC/HL, and LL/HC. A one-way ANOVA for the factor of visual field for each of the three stimulus combinations was not significant (p > 0.05).

**INDIVIDUAL DATA**

The same analyses were performed individually on the VEP amplitude and latency data in each subject. Similar significant results were found in each subject. See Figures 4A and 4B for results in a representative subject. Sample VEP waveforms for one subject for the 3 test conditions (i.e., central field, intact hemifield,
REPEATABILITY

Repeatability results for subject S5 are presented in Figure 4A and 4B for amplitude and latency, respectively. Repeatability was assessed after a period of 1 week. The CV (median, range) across the three visual field and three stimulus combinations were: amplitude (median = 0.05, range = 0.02 to 0.80) and latency (median = 0.01, range = 0.0002 to 0.019), thus suggesting good repeatability.

DISCUSSION

The findings of the present study confirmed and extended the results of previous studies demonstrating that the VEP technique could be used to detect for the presence of hemianopia in stroke patients. Yadav et al. simulated circular, annular, hemi-field, and quadrant absolute visual-field defects in the visually-normal population. They were able to detect and assess reliably all of the aforementioned visual field defect types objectively using the pattern VEP approach. Furthermore, they predicted that the clinical VEP technique would be able to detect and assess actual hemifield defects in clinical patients with stroke, which the present pilot study confirmed. The present findings were also in agreement with Angelelli et al. They too were able to detect hemianopic defects in stroke patients using the VEP technique. Moreover, the present study provided additional evidence that visual field loss in stroke patients could be reliably detected as early as the primary visual cortex (V1), in agreement with Angelelli et al. Lastly, the objective VEP results typically corroborated the subjective clinical perimetric findings.

The present investigation demonstrated for the first time that more subtle stimuli, such as the LC/HL and LL/HC patterns, may be particularly useful and highly sensitive in the detection of hemifield loss in stroke patients. Both the group and individual results revealed that all three stimulus combinations (i.e., HC/HL, LC/HL, LL/HC) were able to detect hemifield loss in the present small sample of individuals with stroke. However, the HC/HL and LL/HC stimulus combinations provided more reliable amplitude results, which were consistent with the clinical visual field findings, as compared to the LC/HL combination (see Figure 3A). Therefore, these two stimulus configurations may be most clinically beneficial in detecting and assessing visual field loss in patients with stroke, especially in those with clinically variable visual field test findings and/or cognitive dysfunction.

Clinical Implications

The pattern VEP technique should prove beneficial in individuals with stroke. This technique could be used as an adjunct to conventional clinical visual field testing to

Figure 5: VEP waveforms for a hemianopic subject: (A) central field, (B) intact hemi-field, and (C) hemianopic field. The amplitude values were 8.64, 7.94, and 1.41 µV, respectively. The “plus sign” represents the cursor for N75, and the other “plus sign” represents the cursor for P100.
detect, assess, and confirm the presence of hemianopia. Due to its objective, rapid, and repeatable nature, the VEP should be especially useful in non-verbal and cognitively-impaired individuals with stroke, as they may not be able to understand the instructions and/or respond reliably to subjective clinical visual-field testing. Therefore, the VEP may be an ideal technique to detect hemianopic field defects in these patients, as it does not require any verbal (e.g., “yes or no”) or physical (e.g., depressing a button) response by the patient. The VEP could also be used to assess the effect of any visual intervention (e.g., eye movement visual scanning training) provided to these stroke patients, as has been demonstrated in mild traumatic brain injury (mTBI). In addition, the VEP could also be extended to the traumatic brain injury (TBI) and pediatric populations exhibiting visual-field defects. Thus, it has the potential to become another “tool” in the clinician’s diagnostic and therapeutic armamentarium for a possible range of visual field abnormalities across a range of abnormal, neurologically-based, visual conditions.

**Proposed VEP Hemianopic Visual-Field Test Protocol**

Based on the results of the present study and another conducted in our laboratory, the following abbreviated clinical VEP visual-field test protocol is proposed in patients with stroke and hemianopia:

I. **Central field (HC/HL)**

II. **Intact hemi-field only (HC/HL)**

III. **Hemianopic field only (HC/HL)**

**Number of trials** – 3 trials (each 20 seconds) should be performed for each test condition, the outlier should be deleted, and remaining two values averaged. Either, additional trials (e.g., 5) or longer test duration (e.g., 45 seconds) could be performed, if needed, for more consistent and less variable responsivity.

**Study Limitations**

There were three possible study limitations. First, sample size was small. However, the effect was robust. Second, only individuals with stroke at the chronic stage were included, but none in either the acute or sub-acute stages were tested. In these earlier stages, any cognitive and/or attentional deficits may be more marked, and hence objective testing may prove to be even more beneficial. Third, individuals with visual neglect were not assessed.

**Future Directions**

There are four possible future directions proposed. First, a similar study should be performed with a larger sample size, such as 30 or more. In addition, hemianopic stroke patients should be included, with and without visual neglect. The VEP might differentiate objectively between those hemianopes with versus without the visual neglect aspect, or just for detection of visual neglect alone. Second, as mentioned above, stroke patients at the acute and sub-acute stages should also be tested to generalize and extend the present pilot findings. Third, smaller visual-field defects (e.g., quadranopsia) should be addressed with the VEP technique and proposed protocol. Lastly, the effect of any visual intervention (e.g., eye movement training) provided to these patients should be assessed to demonstrate possible improvement objectively at the early cortical level.

**CONCLUSION**

The clinical pattern VEP technique was found to be useful in detecting and assessing hemianopic field defects in patients with stroke in the present pilot study. These quantitative visual-field findings were found to be repeatable and reliable. In addition, these objective findings were typically in agreement with the patient’s clinical perimetric results. Therefore, the pattern VEP has the potential to be a useful adjunct technique to test for the presence of visual-field defects in stroke patients.
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